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Ka-Band Transition Product Infrastructure Space Network Demonstration Test Report

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Goddard Space Flight Center
Greenbelt, Maryland

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Preface

This Space Network (SN) Demonstration Test Report states the results of the Ka-Band Transition Product Infrastructure SN Demonstration that was successfully conducted at White Sands Complex in December 2002. Although this demonstration phase was successfully completed, additional follow-on Ka-Band characterization testing will also be conducted in order to fully characterize the SN Ka-band services.

This document is under the internal configuration management of the Ka-Band Transition Product Design Lead. Proposed changes to this document should be submitted to the Ka-Band Transition Product Design Lead along with supportive material justifying the change. Changes to this document shall be made by complete revision. Questions and proposed changes concerning this document shall be addressed to:

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Section 1. Executive Summary

This Space Network (SN) Demonstration Test Report states the results of the Ka-Band Transition Product (KaTP) High Data Rate SN Demonstration that the KaTP test team successfully conducted at the White Sands Complex (WSC) in December 2002. As part of the KaTP project, the KaTP team upgraded space-ground link terminals (SGLTs) at the WSC in order to enable a new SN Ka-Band Single Access Return (KaSAR)-Wideband Intermediate Frequency (IF) Service in conjunction with the new Tracking and Data Relay Satellite (TDRS) HIJ spacecraft. The KaTP test team conducted the SN Demonstration at data rates of 300 Mbps and 600 Mbps with the new IF Service and TDRS-8 spacecraft 650 MHz Channel.

Table 1-1 lists the SN Demonstration measured implementation losses for the uncoded 300 Mbps and uncoded 600 Mbps tests. Table 1-1 also contains the predicted implementation loss values that were calculated from Signal Processing WorkSystem (SPW) end-to-end link simulations. Within the scope of this type of demonstration test, the predicted end-to-end implementation loss values are very close to the measured end-to-end implementation loss values.

Table 1-1. Summary Of TDRS-8 300 Mbps And 600 Mbps SN Demonstration Results

Data Rate	Bit Error Rate	Measured Implementation Loss	Predicted Implementation Loss
300 Mbps	10^{-5}	4.0 dB	Not Available
	10^{-7}	4.9 dB	Not Available
600 Mbps	10^{-5}	9.3 dB	9.8 dB
	10^{-7}	11.9 dB	13.6 dB

The implementation loss increases as BER decreases:

a. For 600 Mbps and a 10^{-5} BER, the total end-to-end implementation loss was 9.3 dB.
b. For 600 Mbps and a 10^{-7} BER, the total end-to-end implementation loss was 11.9 dB.

The test team conducted almost all demonstration testing with the TSI receiver. The TSI receiver data was used to calculate the measured values in Table 1-1. However, the test team was able to collect one end-to-end data point with the GSFC Code 564 receiver. The one data point demonstrates that the Code 564 receiver can support 600 Mbps through the SN.

Both the predicted and measured end-to-end 600 Mbps implementation loss values are relatively high values (e.g., 9.3 dB measured for a 10^{-5} BER). The 9.3 dB implementation loss is significantly high for an operational SN service link. The impact of some distortions on implementation loss may be greater when in combination with a receiver that is not optimized for a particular data rate. During 600 Mbps tests at the Wallops Flight Facility (WFF) in April 2003, WFF personnel discovered that the TSI receiver was not sampling at an optimum point in time during the bit period. Also, improving the gain flatness and phase nonlinearity characteristics of the link is another end-to-end implementation loss reduction option for a

600 Mbps SN data link. WSC is presently procuring channel equalizers to improve the gain flatness of the WSC ground terminal.

The KaTP test team observed two anomalies during the demonstration. The anomalies are as follows:

Anomaly #1: The Link performance varies as a function of KaSAR-Wideband IF Service center frequency. WSC is planning to conduct follow-on characterization testing to more fully characterize that frequency dependent performance. The follow-on characterization testing will include the following:

a. TDRS-HIJ 650 MHz-wide channel performance as a function of center frequency testing which will include 600 Mbps scenarios and gain flatness testing
b. Ka-band 300 Mbps on KaSAR 650 MHz-wide channel tests, Ka-Band 300 Mbps on KaSAR 225 MHz-wide channel tests, and Ku-band 300 Mbps on KuSAR 225 MHz-wide channel tests
c. Demonstration Ka-Band Transmitting System Characteristics Testing

Anomaly #2: Interference occurred on the composite space-ground (SGL) channel at 13.725 GHz when a continuous wave (CW) signal was sent through the KaSAR-wideband channel and dedicated SGL. The 13.725 GHz CW Interference anomaly has been thoroughly analyzed and a solution has been selected. The problem is being corrected by changing the dedicated SGL downlink center frequency from 13.725 GHz to 13.720 GHz. WSC has started the process to make the necessary 650 MHz downconverter LO changes in order to implement the selected solution.

Section 2. Overview

2.1 Background

2.1.1 Reasons For NASA Ka-Band Programs

Prior to the KaTP and TDRS-HIJ projects, the SN provided support to near-Earth science missions at S-Band and Ku-band. Data rates were limited to a maximum of 300 Mbps through the use of the TDRS F1-F7 Ku-Band 225 MHz-wide channels.

NASA initiated the KaTP and TDRS-HIJ projects in an effort to migrate high data rate SN customers to Ka-band. This effort to migrate customers to Ka-band was driven by the following:

a. The SN Ku-Band forward and return links currently operate using a secondary allocation from the International Telecommunications Union (ITU). Therefore, fixed satellite service Earth stations transmitting in the Earth-to-space direction will likely generate increasing interference to the TDRSS Ku-band forward links.

b. NASA's forecasts for Earth Exploration-Satellite mission requirements reflect the need for telemetry data rates up to 1.0 Gbps which exceeds the rate of 300 Mbps that the SN currently supports.

2.1.2 NASA/GSFC Ka-Band Spectrum And TDRS-HIJ Program

The 1992 World Administrative Radio Conference (WARC-92) allocated the 25.25 to 27.5 GHz band to the inter-satellite service, allowing for space-to-space links between a TDRS spacecraft and space research or earth exploration spacecraft. In order to utilize the Ka-band spectrum allocation, NASA procured the TDRS-HIJ spacecraft with capabilities to support a Ka-Band 225 MHz-wide channel and a Ka-Band 650 MHz-wide channel. The current status of the TDRS-HIJ spacecraft is:

a. TDRS-8 was launched in June 2000 and is operational at a 171 degrees West Longitude.
b. TDRS-9 was launched in March 2002 and on-orbit testing is complete.
c. TDRS-10 was launched in December 2002 and on-orbit testing is complete.

2.1.3 Ka-Band Transition Product

In early 2000, the Ka-Band Transition Product (KaTP) was established by the Goddard Space Flight Center (GSFC) Mission Services Program Office to accomplish the following SN goals:

a. Upgrade the WSC infrastructure to implement a new SN Ka-Band Single Access Return (KaSAR)-wideband Intermediate Frequency (IF) service that can use the new TDRS-HIJ 650 MHz-wide channels.
b. Modify the 225 MHz-wide channel equipment at WSC to support both TDRS Ka-Band frequency plan and Space Network Interoperability Panel (SNIP) Ka-Band frequency plan.

2.2 Scope and Objective Of SN Demonstration

During December 2002, the KaTP test team conducted the KaTP SN Demonstration at WSC in order to demonstrate that the new SN KaSAR-Wideband IF Service can use the new TDRS-HIJ 650 MHz-wide channels at data rates up to 600 Mbps. The specific objective of the SN demonstration was to characterize the performance of the KaSAR-Wideband IF Service at data rates up to at least 600 Mbps by:

1. Collecting Eb/No versus BER data and Signal Spectra for Back-To-Back Loop, Medium Loop, Long Loop, End-To-End Test Configurations that Section 3.3.2 and Figure 3-3 detail
2. Determining implementation loss at various BER points by using collected Eb/No versus BER data
3. Assessing effects of subsystem distortions on overall KaSAR-Wideband IF Service by comparing data obtained during different test configurations
4. Using the collected demonstration data to calculate the minimum Prec that a Ka-band customer spacecraft will need to provide at the TDRS SA-1 antenna in order to achieve a specific BER for 600 Mbps when using the TSI receiver.

If time and resources permitted, a secondary goal of the demonstrations was to collect Ku-band and Ka-band 300 Mbps data while using the TDRS-8 225 MHz bandwidth channel in order to compare the performance between the 650 MHz channel and 225 MHz channel.

2.3 Applicable Documents

a. "Ka-Band Transition Product High Data Rate Demonstration Plan", 450-DP-KaTP, Mission Services Program Office, GSFC, November 2002.

b. "Ka-Band Transition Product (KaTP) System Requirements Document (SRD)", 450-SRD-KaTP, Mission Services Program Office, GSFC, March 2002.

c. "Ka-Band Transition Product Management Plan", Original, 453-PMP-KaTP, Mission Services Program Office, GSFC, September 2001.

d. "Ka-Band Transition Product Space Network Demonstration Test Procedures", 450-SNTP-KaTP, Mission Services Program Office, GSFC, September 2002.

e. "Space Network Users' Guide (SNUG)", 450-SNUG, Mission Services Program Office, GSFC, June 2002.

f. TDRSS Ka-Band User Constraint Specifications, SES-450-100027, John Wesdock, et al, ITT Industries, 07 August 2000.

Section 3. Test Approach

3.1 Test System

The system under test was the new SN WSC Ka-Band Infrastructure.

3.2 Requirements

The demonstration satisfied the SN portion of the KaTP demonstration objectives listed in reference [a] that is detailed under paragraph 2.3 of this document.

3.3 Test Overview

3.3.1 General

The KaTP test team, which mainly included WSC and ITT Industries personnel, conducted the SN Demonstration at the NASA WSC by using the TDRS-8, SGLT-2, and a variety of test equipment. A Scheduling Order (SHO), coordinated with the Data Service Management Center (DSMC), was used to schedule KaSAR-wide services via the TDRS-8 spacecraft. Also, by using SHOs, the KaTP test team demonstrated that the KaSAR-wide IF service developed under the KaTP project could be scheduled and monitored through the DSMC. Figure 3-1 is a high-level block diagram of the test configuration that was used during the SN Demonstration.

The Demonstration Ka-Band Transmitting System at the White Sands Ground Terminal (WSGT) transmitted a KaSAR-Wideband (650 MHz bandwidth) signal to the TDRS-8 spacecraft at 25.6 GHz. The TDRS-8 spacecraft received the KaSAR-wideband signal by using its Single Access-1 (SA-1) antenna. The TDRS-8 spacecraft downconverted the Ka-band signal to Ku-band (13.725 GHz) and relayed it to WSC via the TDRS Space-Ground Link (SGL) dedicated downlink. The dedicated downlink signal was received at Ku-band by the Space-Ground Link Terminal-2 (SGLT-2) 19 meter SGL antenna at WSC. SGLT-2 used its new "Ka-band Infrastructure" to downconvert the Ku-band signal to a 1.2 GHz IF. Then the 1.2 GHz IF was sent to a high data rate demonstration receiver via the new IF Switch. Figure 3-2 illustrates the detailed end-to-end test configuration for the SN Demonstration.

The test team used a TSI receiver and a NASA/GSFC developed (Code 564) receiver during the SN Demonstration, but most of the data was collected with the TSI receiver. The test team collected one end-to-end data point with the Code 564 receiver in order to demonstrate that the Code 564 receiver can work with the SN.

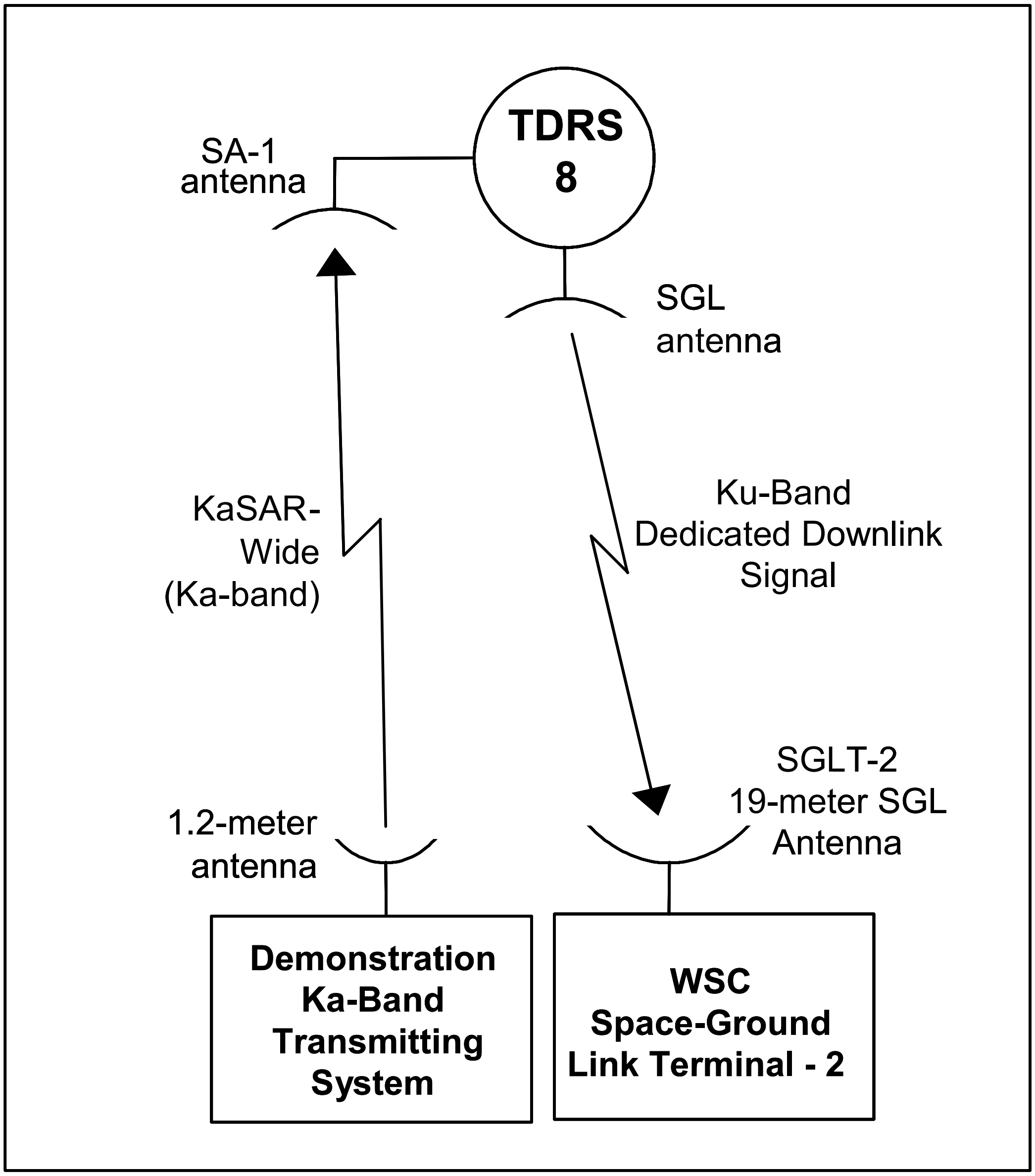

Figure 3-1. SN 600 Mbps High Level Test Configuration

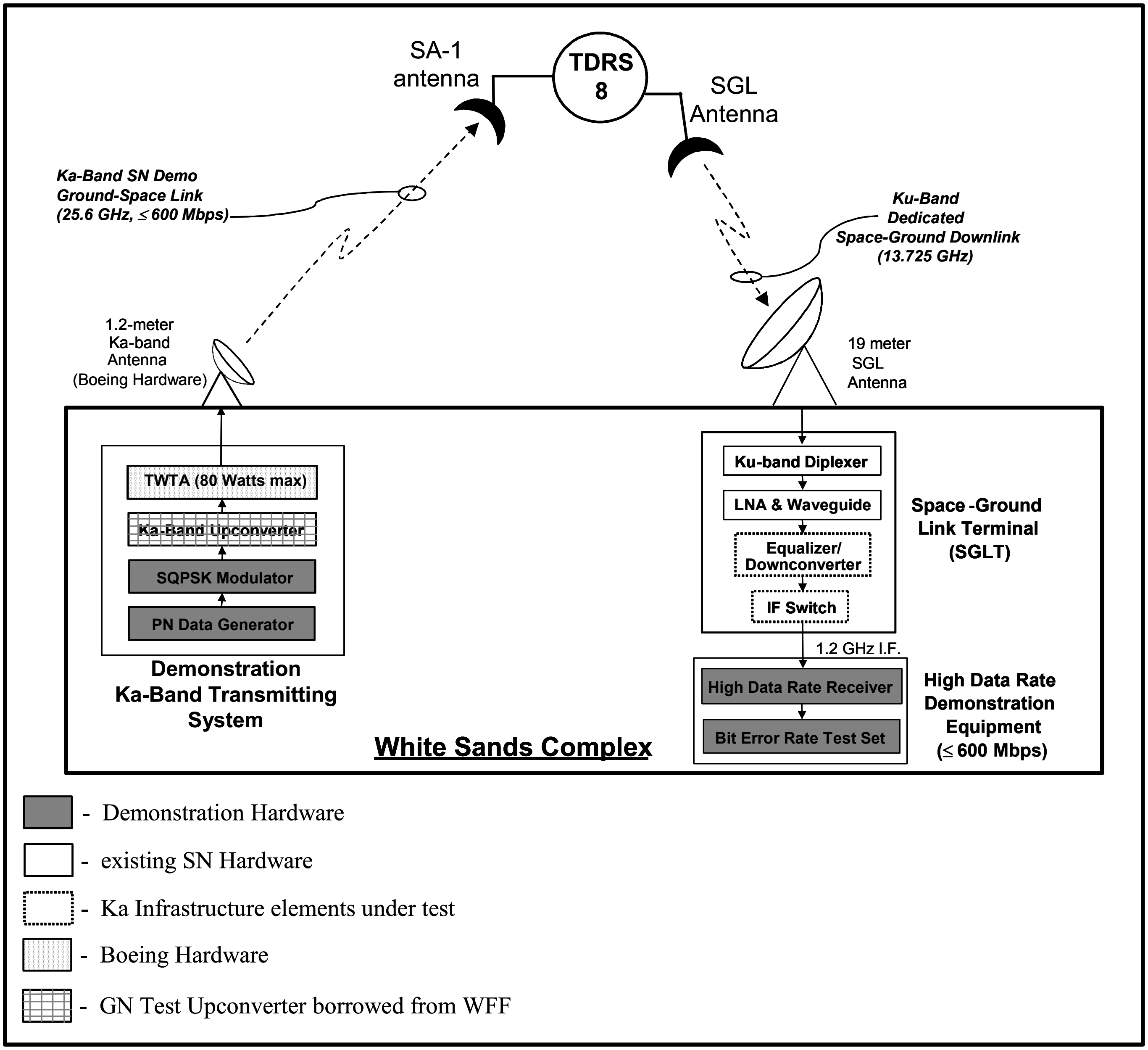

Figure 3-2. SN Demonstration Configuration (End-To-End Tests)

3.3.2 BER Demonstration Details with TSI Receiver

The KaTP test team conducted bit error rate (BER) tests with the TSI receiver to meet the demonstration objective in Section 2.2 above. As depicted in Figure 3-2, the test team used the TDRS-8 spacecraft, the existing TDRS-HIJ KaSA Test Antenna System located at WSGT, and the SGLT-2 located at the Second TDRSS Ground Terminal (STGT). The KaSA Test Antenna was pointed at the TDRS-8 by using current TDRS-8 state vector information. The TDRS-8 SA-1 antenna was pointed at the KaSA Test Antenna by using the WSGT state vector.

The TDRS-HIJ KaSA Test Antenna System, which is owned by Boeing, consists of a 1.2 meter antenna mounted on the roof of the WSGT building and an 80 Watt Ka-band TWTA. The Demonstration Ka-band Transmitting System, which is depicted in Figures 3-1 and 3-2, consisted of the TDRS-HIJ KaSA Test Antenna System, a pseudo-noise (PN) data generator, a TSI high-rate test modulator, and a Ka-band test Upconverter. The Ka-band test Upconverter was borrowed from the Wallops Flight Facility (WFF) Ka-band ground terminal.

In addition to the End-To-End Tests, the KaTP test team also performed BER tests for a back-to-back loop configuration, a medium loop configuration, and a long loop configuration to aid in the assessment of the system design and WSC subsystem and TDRS-8 hardware distortion effects. Figure 3-3 illustrates the back-to-back loop, the medium loop, and long loop test configurations.

To perform a back-to-back loop test as shown in Figure 3-3, the 1.2 GHz output of the modulator was connected to the 1.2 GHz input of the TSI receiver.

To perform a medium loop test as shown in Figure 3-3, the test team used a test Ku-band upconverter to up-convert the 1.2 GHz modulator output to an output frequency identical to the TDRS space-ground link dedicated center frequency (13.725 GHz). The medium loop test consisted of connecting the output of the Ku-band upconverter to the input of the waveguide equalizer. The test team used this medium loop test to measure the performance degradation that is caused by the new Ka-band infrastructure when the equalizer is in the Bypass Mode.

To perform a long loop test as shown in Figure 3-3, the KaTP test team used the test Ku-band upconverter again to upconvert the 1.2 GHz modulator output to an output frequency identical to the TDRS space-ground link dedicated center frequency (13.725 GHz). The long loop test consisted of connecting the output of the Ku-band upconverter to the input of the SGLT-2 Low Noise Amplifier (LNA) at the spare waveguide. The test team used this long loop test to measure the performance degradation that is caused by the LNA, waveguide, and Ka-Band Infrastructure when the equalizer is in its normal operational mode.

The test team performed BER measurements at 300 Mbps and 600 Mbps in order to characterize the systems design and performance. The Ka-band Demonstration Transmitting System used the TSI modulator which was configured for single channel, uncoded SQPSK modulation with a NRZ-L data format on each channel. The TSI modulator generated the same Psuedo Random Bit Stream (PRBS) on each channel, with a ½ bit offset (SQPSK) after a single PRBS was injected into the I-channel input of the TSI modulator. The TSI receiver was configured for

QPSK and individual I and Q channel BER measurements were performed. The KaTP test team fully characterized the system performance by isolating the BER performance on the I channel from the BER performance on the Q channel. The test team calculated the link BER by averaging the I channel and Q channel BERs.

During the end-to-end tests, the KaTP test team varied the output power of the Demonstration Ka-band Transmitting System in order to obtain E_b/N_0 values for BERs from 10^{-5} to 10^{-8}. The test team plotted BER vs. E_b/N_0 curves from the data points. The E_b/N_0 was calculated from the measured C/N_0. A spectrum analyzer was placed in parallel with the receiver input. The test team electronically stored a spectrum analyzer plot on disk for each data rate. Also, the test team calculated the 600 Mbps minimum power received (Prec) at the TDRS SA antenna by using the end-to-end BER, E_b/N_o results, and the calculated implementation loss for the link when using the TSI receiver. See reference [e], Appendix A for a more detailed discussion on Prec.

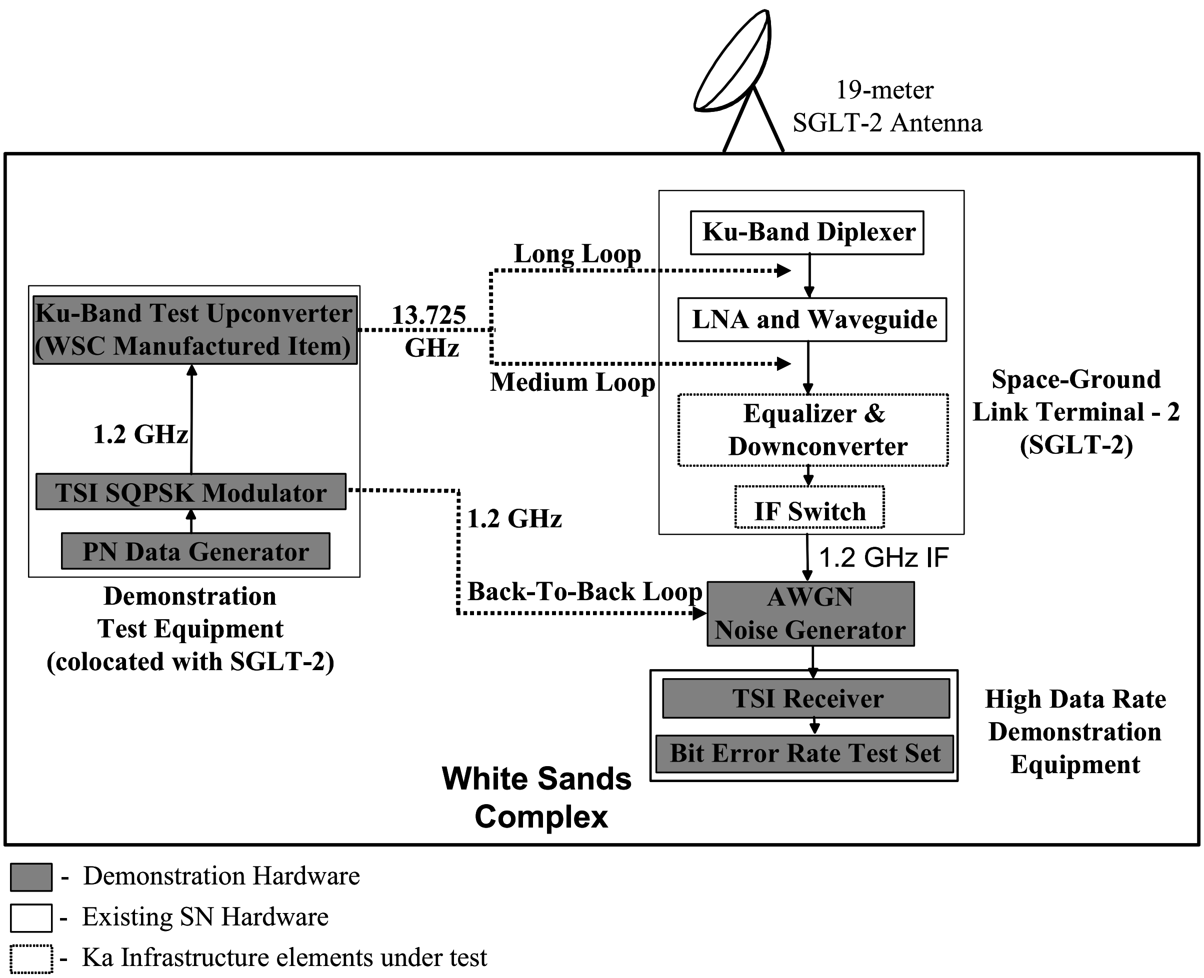

Figure 3-3. SN Loop-Back Test Configurations

In addition to the BER tests, the test team measured the carrier tracking threshold and carrier acquisition threshold during the medium loop tests, the long loop tests, and end-to-end tests.

3.3.3 BER Demonstration Details with Code 564 Receiver

Only limited TDRS-8 spacecraft time was available for Code 564 receiver testing, therefore the KaTP test team, including an engineer from Code 564, collected only one 600 Mbps data point with the Code 564 receiver in the end-to-end test configuration. The end-to-end test configuration for the Code 564 receiver was almost identical to the TSI receiver end-to-end test configuration that is depicted in Figure 3-2. The only difference from the TSI receiver tests was that the modulator was set to QPSK rather than to SQPSK.

The Demonstration Ka-Band Transmitting System used the TSI modulator which was configured for dual channel, uncoded QPSK modulation with a NRZ-L data format on each channel. The Code 564 receiver was configured for QPSK modulation, and individual I and Q channel BER measurements were performed.

Section 4. Test Equipment & Software

Table 4-1 lists all relevant test equipment and software that was used during the KaTP SN Demonstration.

Table 4-1. Test Equipment and Software

ITEM #	TEST EQUIPMENT	MANUFACTURER & TYPE NUMBER	RANGE/SPECIFICATION
1	Spectrum Analyzer	Agilent E4440	1.2 GHz center freq capability for C/N_o measurements Frequency Span Range: 3 Hz to 26.5 GHz. Input impedance = 50 ohms Noise Floor: No = -154 dBm/Hz at 1.2 GHz N-Type female input
2	Bit Error Rate Test System (BERTS)	Anritsu ME522A Receiver	a. 1 to 700 Mbps Capability b. PRN NRZ-L bit stream compatible c. BNC female connectors d. ECL differential to ECL single-ended plug-in module
3	PN Signal Generator	Anritsu ME522A Transmitter	a. Generate data rates from 1 Mbps to 700 Mbps b. PRN NRZ-L bit stream compatible with Anritsu BERTS (2^{23}-1) c. BNC female connectors d. ECL single-ended to ECL differential plug-in module
4	SQPSK Modulator	TSI Telsys	a. SQPSK modulation b. Single channel input for 50 Mbps to 600 Mbps NRZ-L data input c. Provide $0.5xT_b$ channel offset prior to modulation d. 1.2 GHz output e. Output Level: -15 to +4 dBm
5	Ku-Band Upconverter (medium loop and long loop tests, see Figure 3-3)	WSC manufactured Test equipment. (Mixer and FSY Microwave Filter unit)	a. 1.2 GHz to (13725 MHz) Ku-Band frequency translation b. 650 MHz bandwidth, maximum c. SMA female input connector d. SMA output connector
6	Ka-Band Upconverter (end-to-end test with TDRS-8 only, see Figure 3-2.)	GN Ka-band Test Upconverter (Borrow from WFF)	a. 1.2 GHz to Ka-Band SNIP demo frequency translation (25.6 GHz) b. 1.2 GHz bandwidth c. N-Type female input connector d. K-Connector female output connector with adapter
7	Ka-Band Upconverter control software	Miteq Labview software for WFF upconverter unit	a. Software runs on any PC with any Windows 95 or better operating system.
8	KaSA Test Antenna System at WSGT with TWTA	Boeing (formally Hughes)	a. Ka-Band TWTA (max. output power = 80 W) b. 1.2 meter Ka-Band antenna c. Antenna Gain = 47 dB d. EIRP of antenna/TWTA = 66 dBW

ITEM #	TEST EQUIPMENT	MANUFACTURER & TYPE NUMBER	RANGE/SPECIFICATION
9	Code 564 High Data Rate Receiver	GSFC Code 564 High Rate Digital Receiver	a. 1.2 GHz IF input with discrete component analog front-end b. QPSK, NRZ-L demodulation and bit synchronization only, no SQPSK available c. Separate I and Q channel outputs (data and clock) d. Fixed data rates up to 600 Mbps (300 Mbps each channel) e. No data format conversion f. No I/Q channel combining
10	TSI High Data Rate Receiver	TSI	a. 1.2 GHz IF input b. QPSK demodulation and bit synchronization c. Separate I and Q channel outputs for QPSK d. Receiver is programmable to operate at any data rate up to 600 Mbps (300 Mbps each channel)
11	Power Divider (1 input/ 2 outputs)	Provided by WSC	a. Can operate at 1.2 GHz b. SMA female connectors
12	15 cables with SMA male connectors that operate up to 1.2 GHz	Provided by WSC and WFF	a. Can operate at 1.2 GHz b. 0.5 –1.0 meter length
13	Adapters	Provided by WSC Lab Adapter cabinet/trays.	a. 8 BNC male to SMA female adapters for Anritsu receiver and transmitter. b. Two N-Type male to SMA female adapters for spectrum analyzer use.
14	AWGN Generator	Noise/Com, model NC6112 (provided by WSC)	a. Has Signal Combiner option. b. Has 110 dB attenuator in 1 dB steps option.

Section 5. Test Conduct

5.1 KaTP Test Team Personnel

The KaTP test team included the following personnel:

- KaTP Test Director (ITT Industries)
- WSC Engineering personnel
- WSC Operations personnel
- GSFC Code 564 Engineer

5.1.1 Test Director Responsibilities

- Overall responsibility for demonstration tests and operation of TSI receiver, TSI modulator, and Ka-band upconverter
- Conducted step-by-step demonstration procedures along with WSC personnel
- Documented demonstration test results

5.1.2 WSC Engineering Personnel Responsibilities

- Overall responsibility for WSC and demonstration equipment integration, check-out, and operation
- Conducted step-by-step demonstration procedures along with test director
- Supported test director in documenting results
- Interfaced with operations personnel to ensure required TDRS-8 time was scheduled via a SHO

5.1.3 WSC Operations Personnel Responsibilities

Overall responsibility for operations support, which included producing the Scheduling Order (SHO) to schedule the required TDRS-8 time.

5.1.4 GSFC Code 564 Engineer Responsibility

A GSFC Code 564 engineer was responsible for the Code 564 receiver operation.

5.2 Procedure Control

5.2.1 During Test

During the test, the KaTP test director redlined the official SN Demonstration Test Procedure.

5.2.2 After Test

The test director incorporated the redlined changes into the final test procedure.

Section 6. Demonstration Results With TSI Receiver

6.1 Introduction

This section presents the detailed demonstration results for the SN Demonstration when using the TSI receiver. Figure 6-1 depicts the relevant portions of the WSC SGLT-2 including the new "Ka-Band Infrastructure". Later figures in this section depict the Demonstration Ka-Band Transmitting System at WSGT, the TSI receiver, and other demonstration test equipment.

Before conducting the demonstration, WSC personnel verified that the new "Ka-Band Infrastructure" was operating properly and within the specifications defined in the KaTP Systems Requirements Document (SRD). Therefore, the BER demonstration started after the relevant "Ka-Band Infrastructure" system acceptance tests were completed.

The KaTP test team conducted the SN Demonstration by building up the test configurations in stages to reach the final End-To-End Test Configuration. Figure 6-2 depicts the different test configuration stages.

Section 6.2 describes the results of the "Back-To-Back Loop" tests at 300 Mbps and 600 Mbps. As Figure 6-2 depicts, the test configuration consisted of the TSI modulator transmitting into the TSI receiver. The test team conducted this test on the bench at the WSC facilities. During the Back-To-Back tests, the E_b/N_0 at BERs from 10^{-5} to 10^{-8} was measured.

Section 6.3 describes the results of the "Medium Loop" tests at 300 Mbps and 600 Mbps. In addition to the receiver and modulator, this test included the WSC test Ku-band upconverter, waveguide equalizer, downconverter, and IF Switch. The test was conducted in the STGT Ground Control Equipment (GCE) room with the SGLT-2 equipment.

Section 6.4 describes the results of the "Long Loop" tests at 300 Mbps and 600 Mbps. In addition to the equipment in the medium loop, this test included the LNA and waveguide. The test was also conducted with SGLT-2.

Section 6.5 describes the results of the "End-To-End" tests at 300 Mbps and 600 Mbps. This test included the TDRS-8 spacecraft, Demonstration Ka-Band Transmitting System, and SGLT-2 equipment. During the end-to-end tests only, a SHO was used to reserve the KaSAR-Wideband (650 MHz Channel) IF service via TDRS-8. WSC operations personnel assisted demonstration test personnel with producing the required SHOs.

The long loop tests did not require a SHO because the KaTP test team used the spare waveguide to perform this test while customers were supported on the prime waveguide. Also, the medium loop tests did not require a SHO, and did not impact normal TDRS operations. The test team used the Additive White Gaussian Noise (AWGN) generator during the back-to-back loop, medium loop, and long loop tests.

During the medium loop, long loop, and end-to-end tests, the KaTP test team recorded a spectrum analyzer plot on disk for each data rate.

For each data rate, the test team varied the E_b/N_0 for BERs from 10^{-5} to 10^{-8}. In addition to BER tests, the test team measured the carrier tracking threshold and carrier acquisition threshold during the medium loop tests, long loop tests, and end-to-end tests.

Section 6.6 contains the calculated minimum Prec at the TDRS SA-1 antenna for the 600 Mbps link when using the TSI receiver. The test team used the End-To-End BER, E_b/N_0 results, and calculated implementation loss for the link when using the TSI receiver in order to determine the Prec values in Section 6.6. See reference [e], Appendix A for a more detailed discussion on Prec.

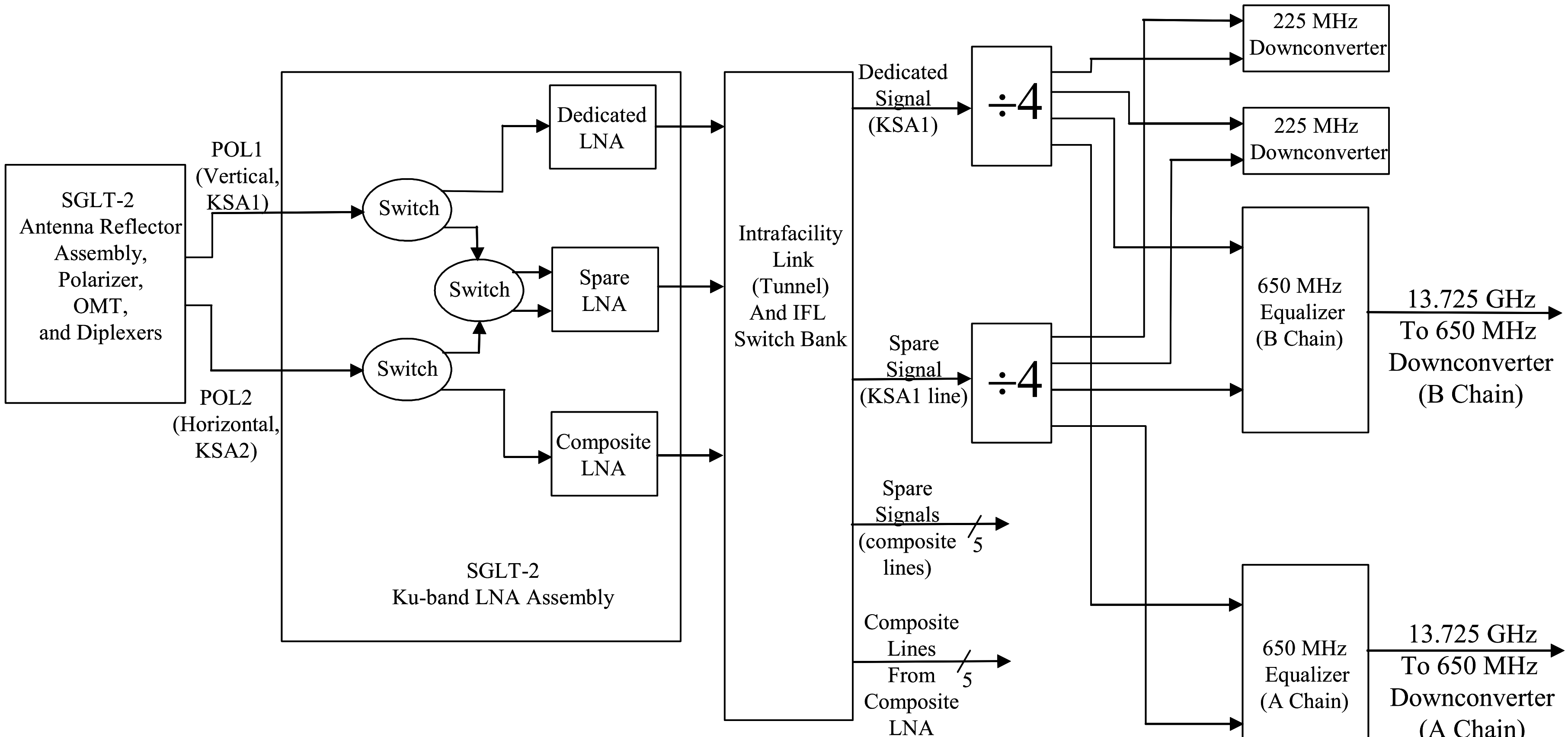

Figure 6-1. SGLT-2 Permanent Ka-Band Infrastructure Configuration (Sheet 1 of 2)

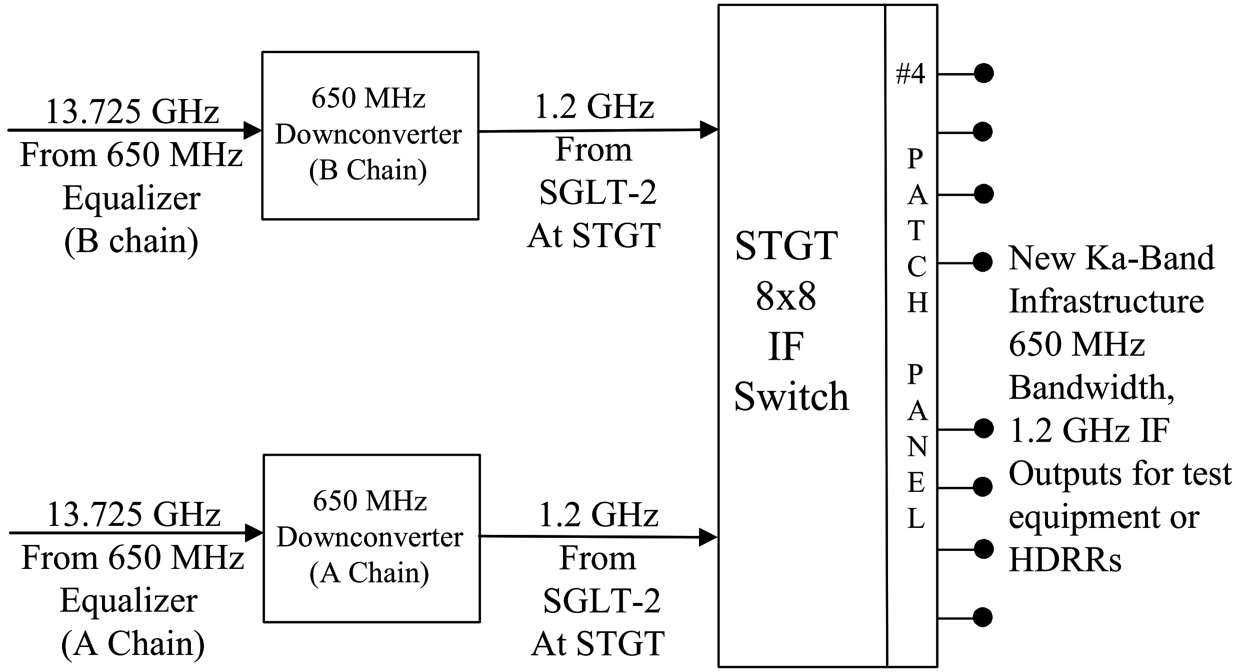

Figure 6-1. SGLT-2 Permanent Ka-Band Infrastructure Configuration (Sheet 2 of 2)

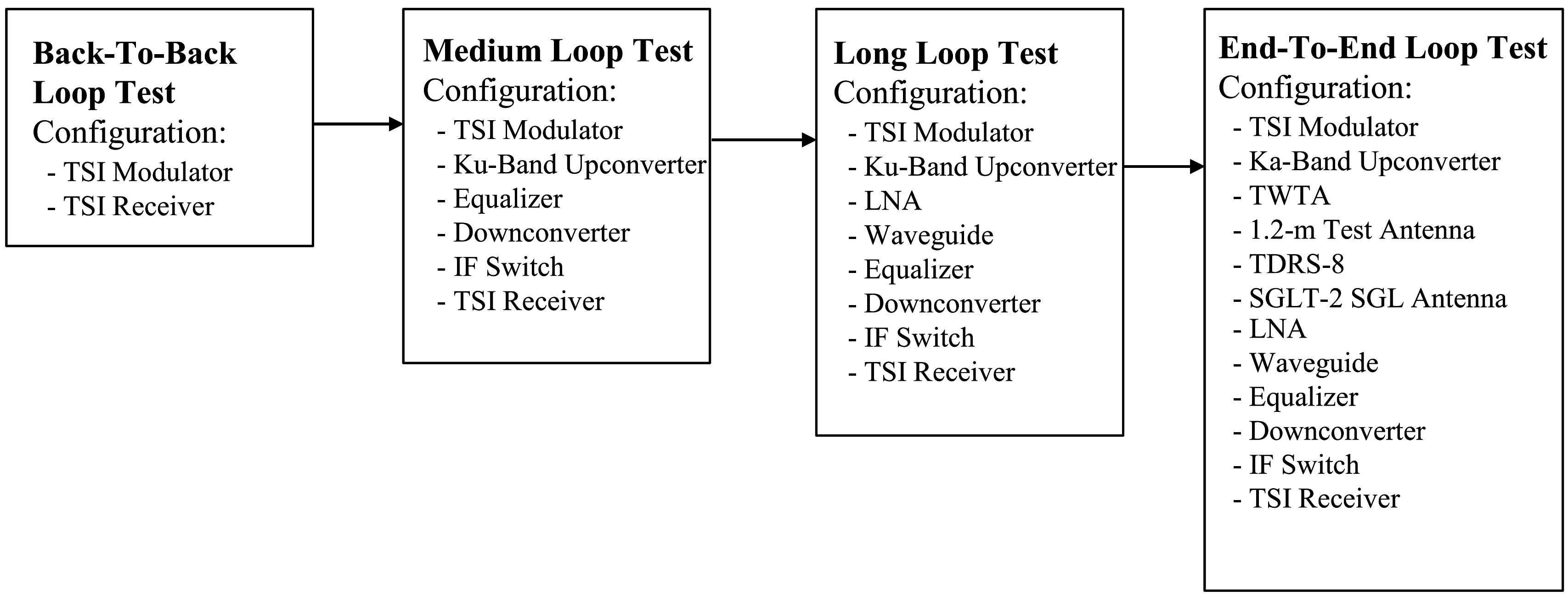

Figure 6-2. Test Configuration Stages

6.2 Back-To-Back Receiver Testing

This section describes the detailed results of the Back-To-Back Loop tests at 300 Mbps and 600 Mbps. Figure 6-3 depicts the detailed back-to-back test configuration. This test consisted of the TSI modulator transmitting into the TSI receiver while the units were on a bench at the WSC facilities. During the back-to-back tests, the KaTP test team measured the E_b/N_0 values for BERs from 10^{-5} to 10^{-8}. The PN data generator provided data and clock signals to the TSI modulator. The signal level at the TSI receiver input was held constant at about -15 dBm which simulated the signal level provided at the IF Switch output. The KaTP test team used the noise generator to generate the different Eb/No values. The spectrum analyzer was used to make C/No measurements. The test team calculated the Eb/No values from the C/No measurement data.

Table 6-1 summarizes the test equipment settings and configurations that were used for the 300 Mbps and 600 Mbps tests.

Table 6-1. Back-To-Back 300 Mbps & 600 Mbps Test Unit Settings/Configurations

Unit Name	300 Mbps Unit Settings/Configurations	600 Mbps Unit Settings/Configurations
PN Data Generator	300 Mbps Differential ECL output NRZ-L Data Format PRBS of 2^{23}-1	600 Mbps Differential ECL output NRZ-L Data Format PRBS of 2^{23}-1
TSI Modulator	300 Mbps Differential ECL input SQPSK, IF = 1.2 GHz -3 dBm Output Power NRZ-L Data Format	600 Mbps Differential ECL input SQPSK, IF = 1.2 GHz -3 dBm Output Power NRZ-L Data Format
Noise/Com Noise Generator	1.2 GHz broadband noise Initial Attenuation = 0 dB (C/No varied by increasing attenuation which varied noise level)	1.2 GHz broadband noise Initial Attenuation = 0 dB (C/No varied by increasing attenuation which varied noise level)
TSI Receiver	150 Mbps on each Channel Differential ECL output QPSK NRZ-L Data Format	300 Mbps on each Channel Differential ECL output QPSK NRZ-L Data Format
Bit Error Rate Test Set	150 Mbps (Measured I&Q receiver channels separately) Differential ECL input NRZ-L Data Format PRBS of 2^{23}-1	300 Mbps (Measured I&Q receiver channels separately) Differential ECL input NRZ-L Data Format PRBS of 2^{23}-1
Spectrum Analyzer	Center Frequency = 1.2 GHz Resolution Bandwidth = 1.0 MHz	Center Frequency = 1.2 GHz Resolution Bandwidth = 1.0 MHz

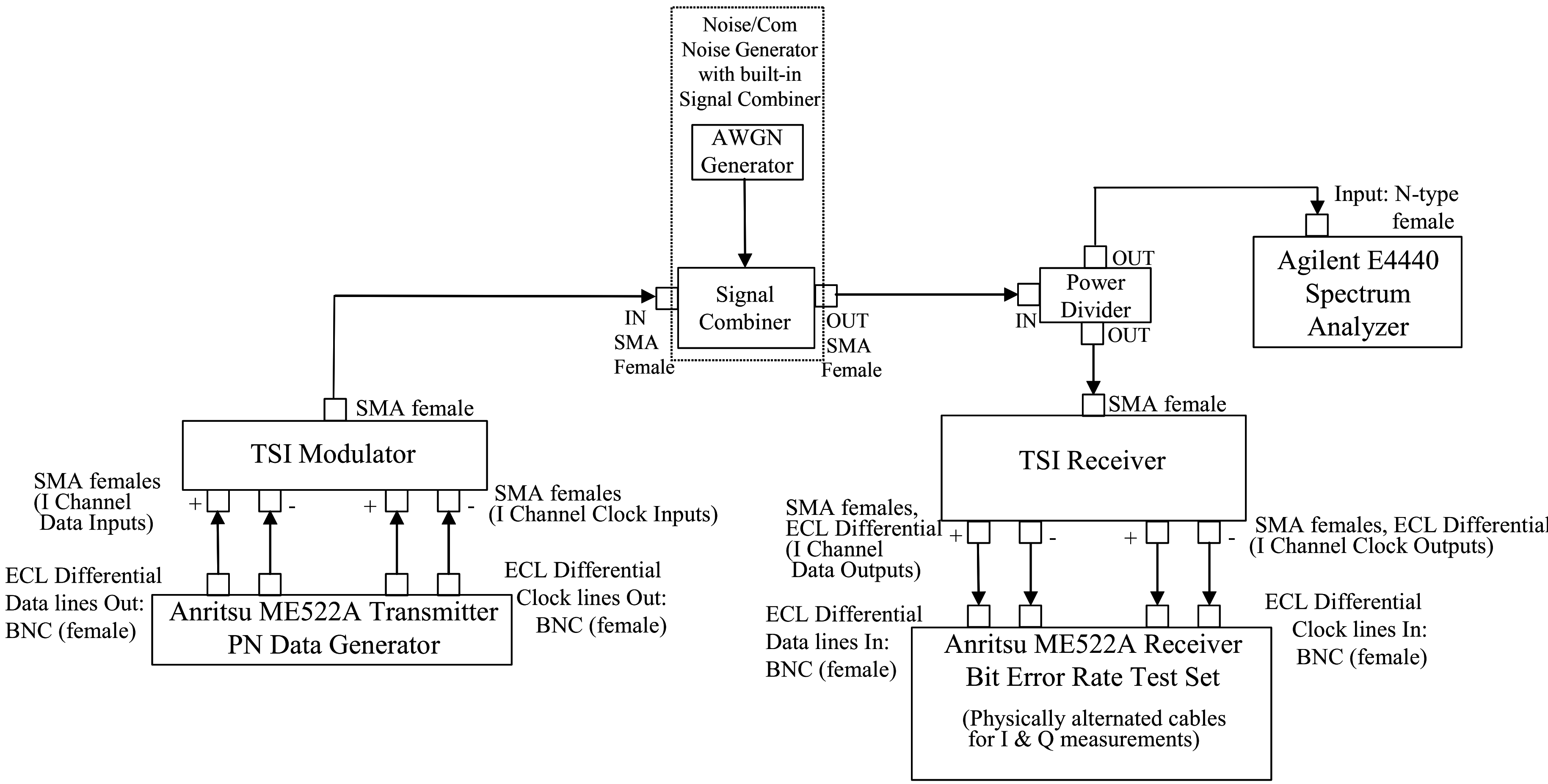

Figure 6-3. Back-To-Back Test Configuration

Figure 6-4 depicts the 300 Mbps and 600 Mbps Eb/No results for the back-to-back tests. As stated in paragraph 3.3.2, the test team measured the I & Q channel BERs separately. Then, the I & Q channel results were averaged in order to generate the curves in Figure 6-4. Table 6-2 lists the implementation loss results for the 300 Mbps and 600 Mbps tests. Implementation loss was calculated by subtracting the theoretical curve from the actual measured curve.

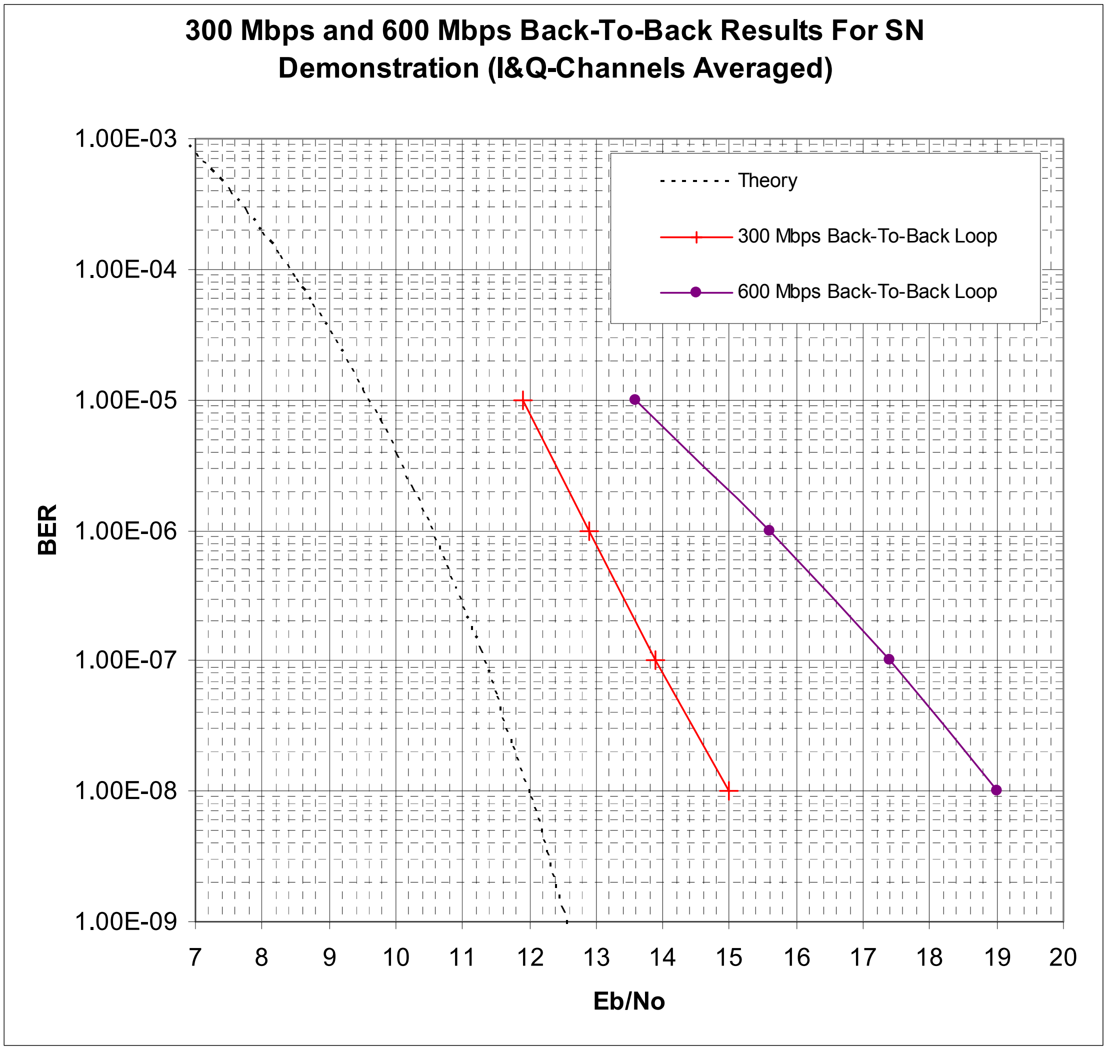

Figure 6-4. Back-To-Back 300 Mbps and 600 Mbps Eb/No Results

Table 6-2. Back-To-Back 300 Mbps and 600 Mbps Implementation Loss Results

Data Rate	BER	Implementation Loss
300 Mbps	10^{-5}	2.3 dB
	10^{-7}	2.6 dB
600 Mbps	10^{-5}	4.0 dB
	10^{-7}	6.1 dB

6.3 Medium Loop Test

This section describes the detailed results of the medium loop tests at 300 Mbps and 600 Mbps. Figure 6-5 depicts the detailed medium loop test configuration. In addition to the receiver and modulator, this test included the WSC test Ku-band upconverter, waveguide equalizer, downconverter, and IF Switch. The waveguide equalizer was set in the Bypass mode because the waveguide was not used during the medium loop test. During the medium loop tests, the KaTP test team measured the E_b/N_0 values for BERs from 10^{-5} to 10^{-8}. The PN data generator provided data and clock signals to the TSI modulator. The KaTP test team used the noise generator to generate the different Eb/No values. The spectrum analyzer was used to make C/No measurements. The test team calculated the Eb/No values from the C/No measurement data.

Table 6-3 summarizes the test equipment settings and configurations that were used for the 300 Mbps and 600 Mbps tests.

Table 6-3. Medium Loop 300 Mbps & 600 Mbps Test Unit Settings/Configurations

Unit Name	300 Mbps Unit Settings/Configurations	600 Mbps Unit Settings/Configurations
PN Data Generator	300 Mbps Differential ECL output NRZ-L Data Format PRBS of 2^{23}-1	600 Mbps Differential ECL output NRZ-L Data Format PRBS of 2^{23}-1
TSI Modulator	300 Mbps Differential ECL input SQPSK, IF = 1.2 GHz +4 dBm Output Power NRZ-L Data Format	600 Mbps Differential ECL input SQPSK, IF = 1.2 GHz +4 dBm Output Power NRZ-L Data Format
Noise/Com Noise Generator	1.2 GHz broadband noise Initial Attenuation = 0 dB (C/No varied by increasing attenuation which varied noise level)	1.2 GHz broadband noise Initial Attenuation = 0 dB (C/No varied by increasing attenuation which varied noise level)
TSI Receiver	150 Mbps on each Channel Differential ECL output QPSK NRZ-L Data Format	300 Mbps on each Channel Differential ECL output QPSK NRZ-L Data Format
Bit Error Rate Test Set	150 Mbps (Measured I&Q receiver channels separately) Differential ECL input NRZ-L Data Format PRBS of 2^{23}-1	300 Mbps (Measured I&Q receiver channels separately) Differential ECL input NRZ-L Data Format PRBS of 2^{23}-1
Spectrum Analyzer	Center Frequency = 1.2 GHz Resolution Bandwidth = 1.0 MHz	Center Frequency = 1.2 GHz Resolution Bandwidth = 1.0 MHz
650 MHz Equalizer (B Chain)	Bypass Mode Spare Waveguide Input	Bypass Mode Spare Waveguide Input

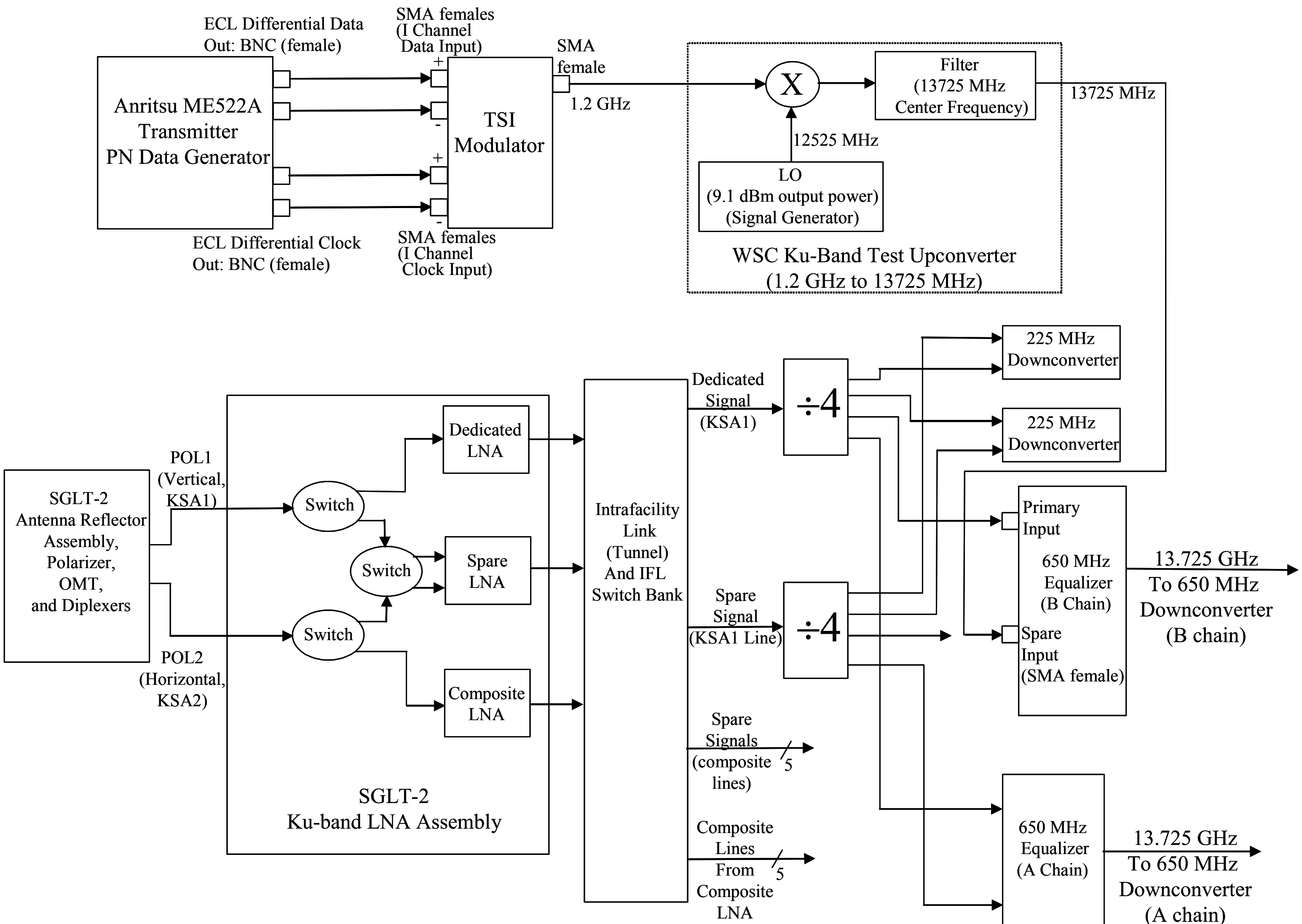

Figure 6-5. Medium Loop Test Configuration (Sheet 1 of 2)

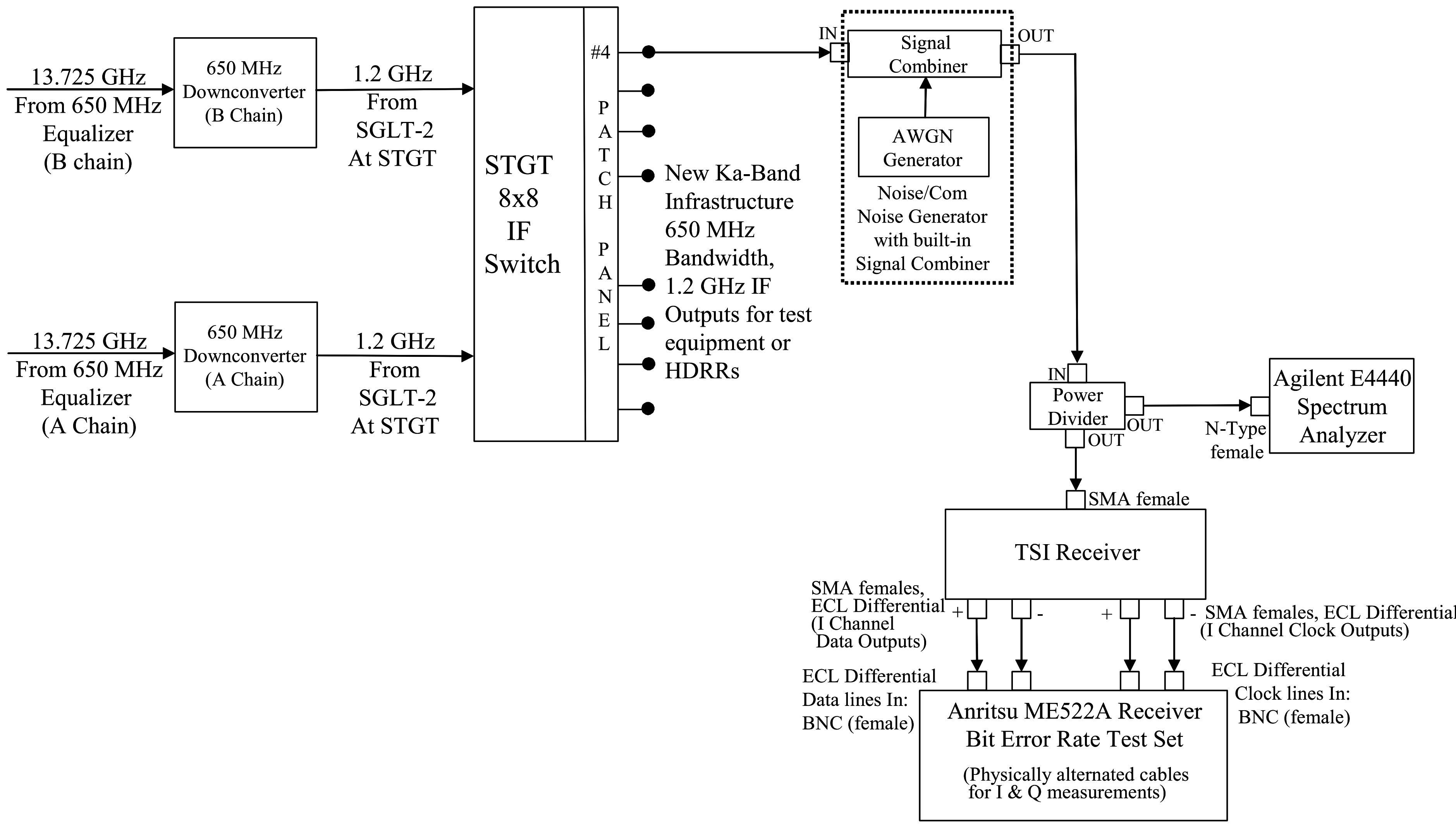

Figure 6-5. Medium Loop Test Configuration (Sheet 2 of 2)

Figure 6-6 depicts the 300 Mbps and 600 Mbps Eb/No results for the medium loop tests. As stated in paragraph 3.3.2, the test team measured the I & Q channel BERs separately. Then, the I & Q channel results were averaged in order to generate the curves in Figure 6-6.

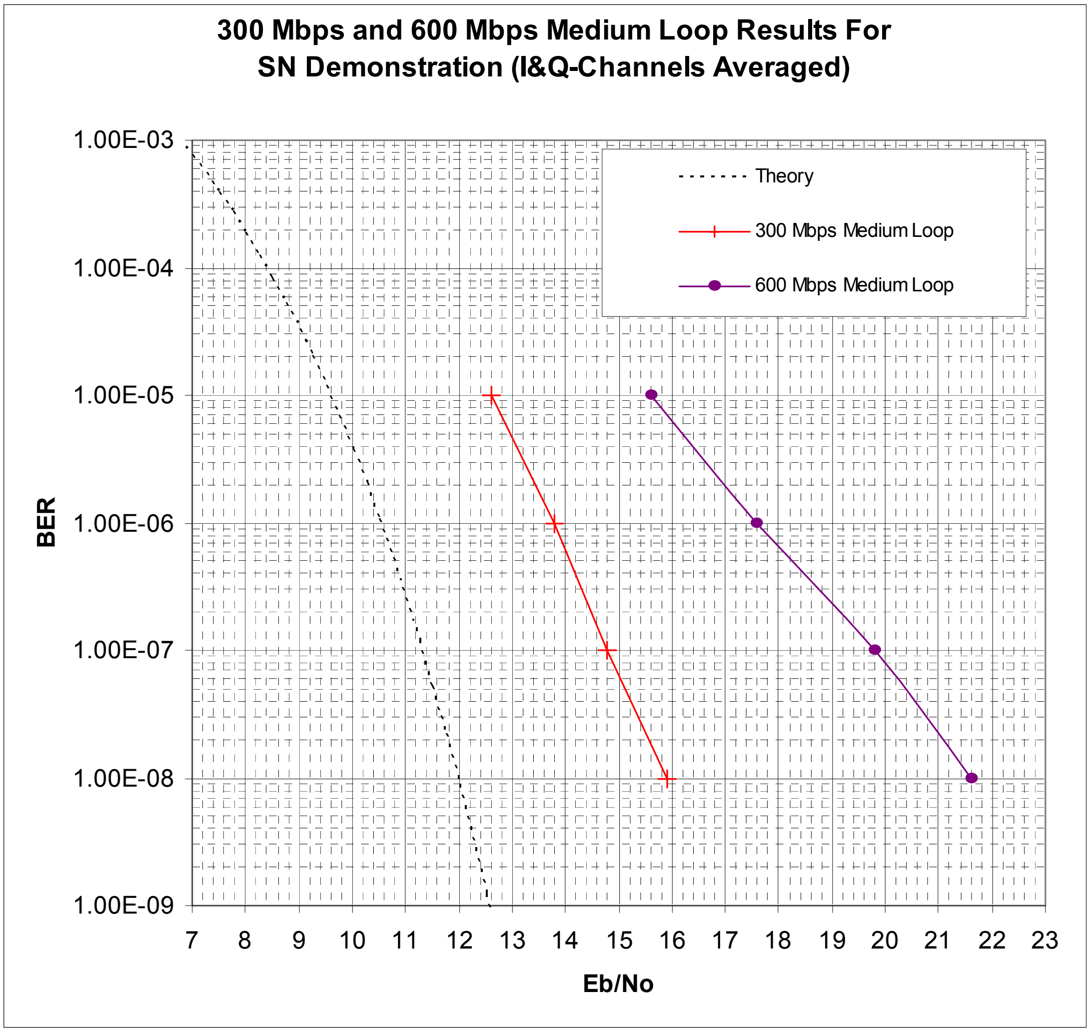

Figure 6-6. Medium Loop 300 Mbps and 600 Mbps Eb/No Results

Table 6-4 lists the implementation loss results for the 300 Mbps and 600 Mbps tests. Implementation loss was calculated by subtracting the theoretical curve from the actual measured curve. In addition to the BER tests, the test team measured the carrier tracking threshold (Eb/No and C/No when carrier lock lost) and carrier acquisition threshold (Eb/No and C/No when carrier lock acquired). Table 6-5 lists the carrier lock loss and carrier lock acquisition results. The test team used the carrier lock indicator on the TSI receiver display to collect the carrier lock data.

Figure 6-7 and Figure 6-8 depict the spectrum analyzer plots for the 300 Mbps and 600 Mbps Medium Loop tests. Figure 6-7 is noisier than the other spectrum plots in this document because the "Average" function was set to OFF.

Table 6-4. Medium Loop 300 Mbps and 600 Mbps Implementation Loss Results

Data Rate	BER	Implementation Loss
300 Mbps	10^{-5}	3.0 dB
	10^{-7}	3.5 dB
600 Mbps	10^{-5}	6.0 dB
	10^{-7}	8.5 dB

Table 6-5. Medium Loop 300 Mbps and 600 Mbps Carrier Lock Results

Data Rate	Eb/No At Carrier Lock Loss	C/No At Carrier Lock Loss	Eb/No At Carrier Lock Acquisition	C/No At Carrier Lock Acquisition
300 Mbps	1.0 dB	85.8 dB-Hz	2.0 dB	86.8 dB-Hz
600 Mbps	0.5 dB	88.3 dB-Hz	1.5 dB	89.3 dB-Hz

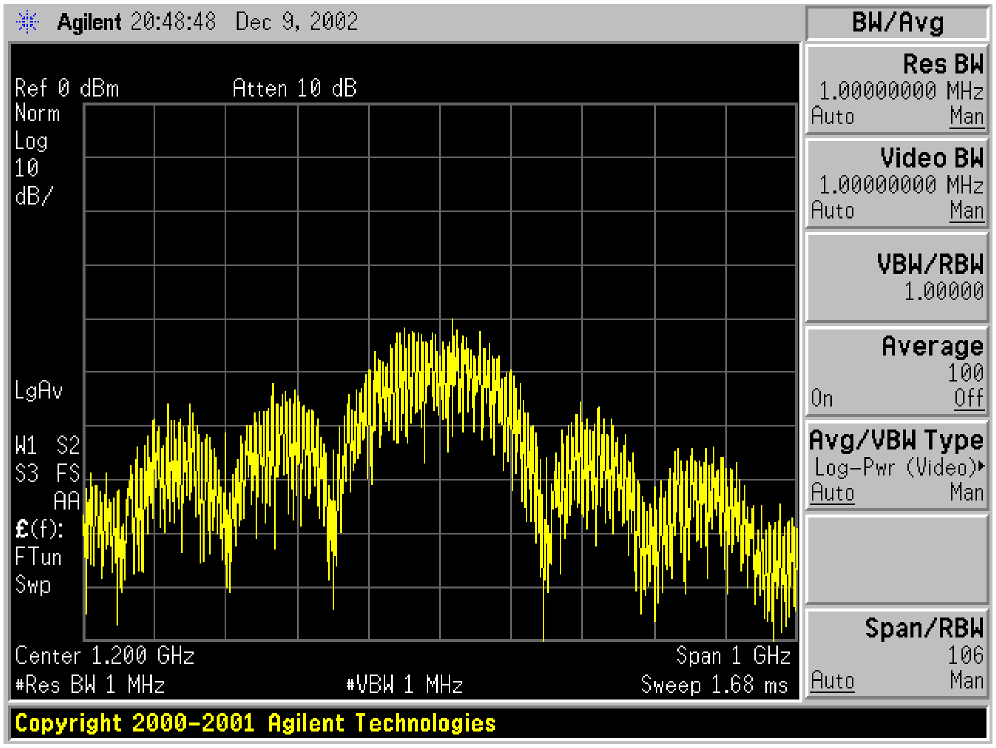

Figure 6-7. Spectrum Analyzer Plot, Medium Loop Test, 300 Mbps

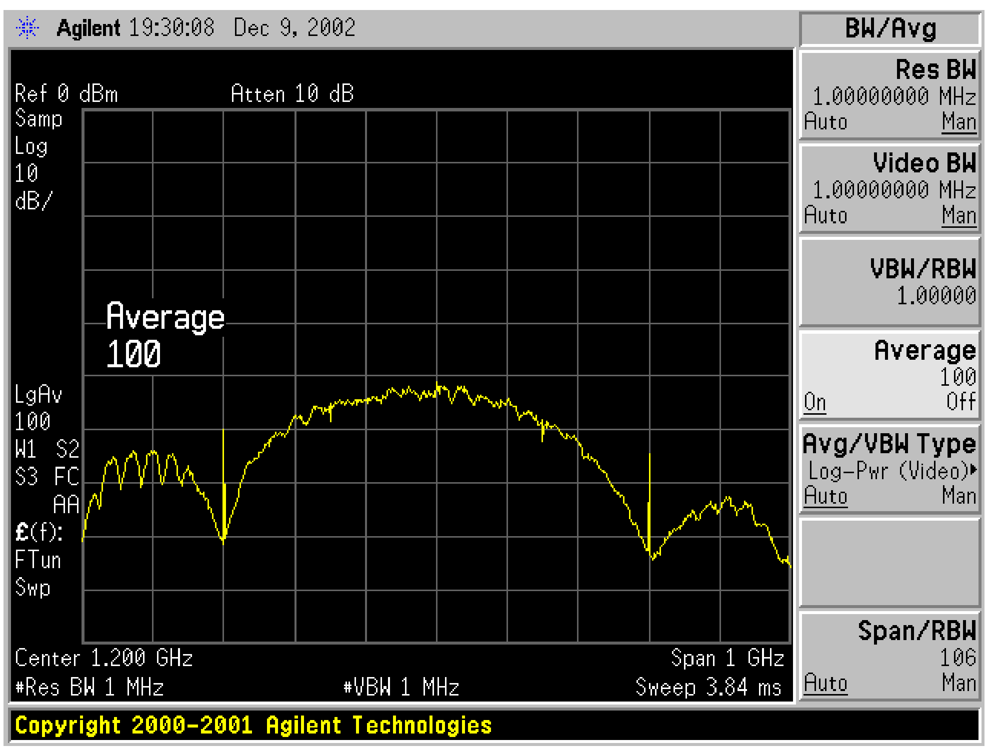

Figure 6-8. Spectrum Analyzer Plot, Medium Loop Test, 600 Mbps

6.4 Long Loop Test

This section describes the detailed results of the long loop tests at 300 Mbps and 600 Mbps. Figure 6-9 depicts the detailed Long Loop test configuration. In addition to the equipment in the medium loop, this test included the SGLT-2 spare LNA and spare waveguide. The equalizer was set in its normal mode for the spare waveguide. During the long loop tests, the KaTP test team measured the E_b/N_0 values for BERs from 10^{-5} to 10^{-8}, but a 10^{-8} BER was not quite achievable at 600 Mbps because poor Q-Channel performance occurred at 600 Mbps. Therefore, the lowest achievable BER for 600 Mbps during the long loop test when combining the I & Q channels was 3.0E-08.

The test configuration included a 40 dB fixed attenuator at the output of the test Ku-band upconverter in order to prevent the upconverter from saturating the SGLT-2 spare LNA.

The 3.0E-08 minimum BER limit most likely occurred because the available fixed attenuator and test upconverter in combination with the already relatively high implementation loss receiver produced a BER floor. A higher quality fixed attenuator, and improvements to the test upconverter and TSI receiver could lower the BER floor that was experienced during this long loop test. However, this long loop BER floor did not impact the overall SN Demonstration because the KaTP test team did not require the fixed attenuator or the test upconverter for the End-To-End tests, which were the most important part of the SN Demonstration. The KaTP team conducted the back-to-back loop tests, medium loop tests, and long loop tests to assess the effects of subsystem signal distortions on the overall KaSAR-Wideband IF Service.

The PN data generator provided data and clock signals to the TSI modulator. The KaTP test team used the noise generator to generate the different Eb/No values. The spectrum analyzer was used to make C/No measurements. The test team calculated the Eb/No values from the C/No measurement data.

Table 6-6 summarizes the test equipment settings and configurations that were used for the 300 Mbps and 600 Mbps tests.

Table 6-6. Long Loop 300 Mbps & 600 Mbps Test Unit Settings/Configurations

Unit Name	300 Mbps Unit Settings/Configurations	600 Mbps Unit Settings/Configurations
PN Data Generator	300 Mbps Differential ECL output NRZ-L Data Format PRBS of 2^{23}-1	600 Mbps Differential ECL output NRZ-L Data Format PRBS of 2^{23}-1
TSI Modulator	300 Mbps Differential ECL input SQPSK, IF = 1.2 GHz +4 dBm Output Power NRZ-L Data Format	600 Mbps Differential ECL input SQPSK, IF = 1.2 GHz +4 dBm Output Power NRZ-L Data Format
Noise/Com Noise Generator	1.2 GHz broadband noise Initial Attenuation = 0 dB (C/No varied by increasing attenuation which varied noise level)	1.2 GHz broadband noise Initial Attenuation = 0 dB (C/No varied by increasing attenuation which varied noise level)
TSI Receiver	150 Mbps on each Channel Differential ECL output QPSK NRZ-L Data Format	300 Mbps on each Channel Differential ECL output QPSK NRZ-L Data Format
Bit Error Rate Test Set	150 Mbps (Measured I&Q receiver channels separately) Differential ECL input NRZ-L Data Format PRBS of 2^{23}-1	300 Mbps (Measured I&Q receiver channels separately) Differential ECL input NRZ-L Data Format PRBS of 2^{23}-1
Spectrum Analyzer	Center Frequency = 1.2 GHz Resolution Bandwidth = 1.0 MHz	Center Frequency = 1.2 GHz Resolution Bandwidth = 1.0 MHz
650 MHz Equalizer (B Chain)	Normal Mode Spare Waveguide Input	Normal Mode Spare Waveguide Input

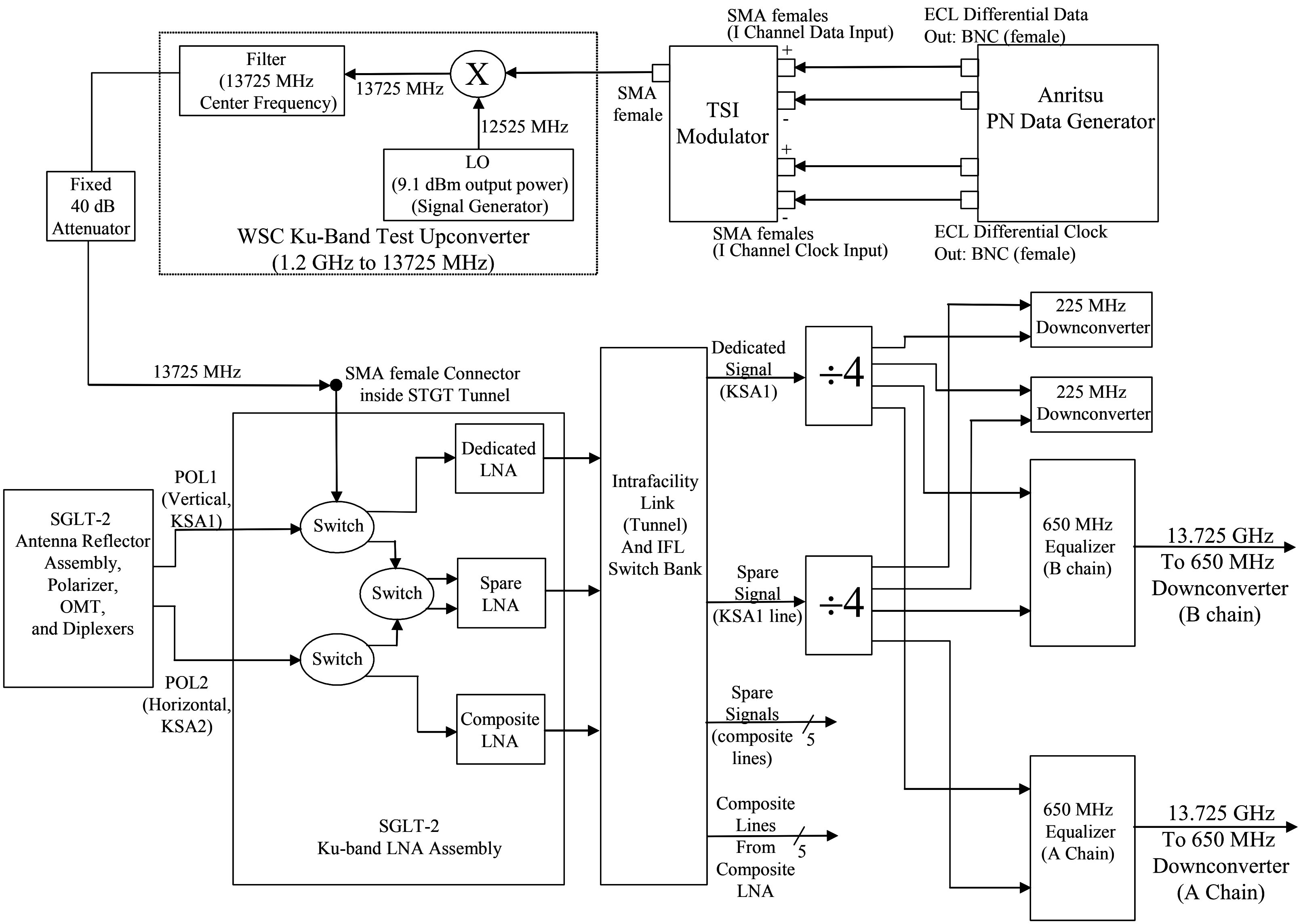

Figure 6-9. Long Loop Test Configuration (Sheet 1 of 2)

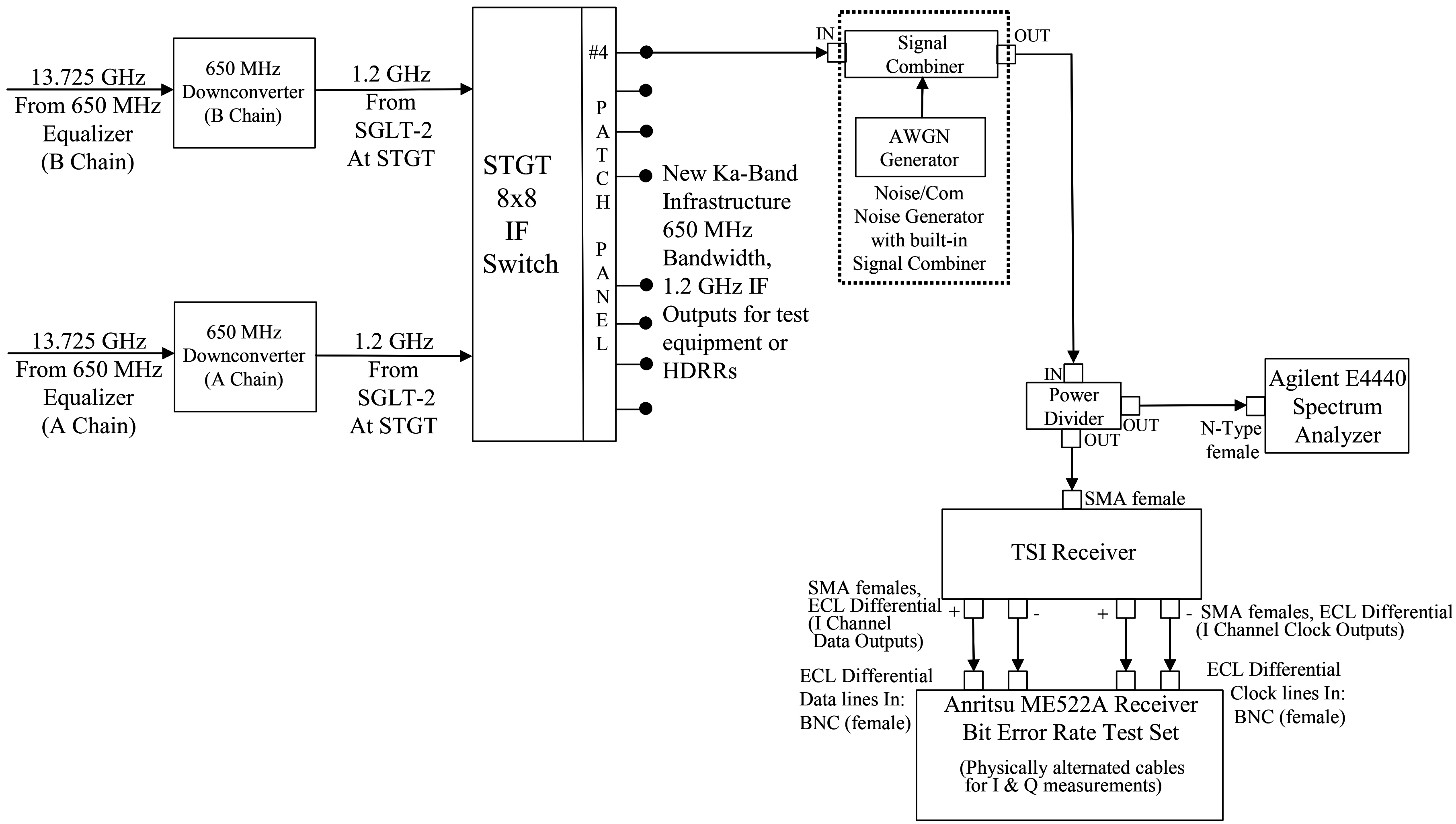

Figure 6-9. Long Loop Test Configuration (Sheet 2 of 2)

Figure 6-10 depicts the 300 Mbps and 600 Mbps Eb/No results for the long loop tests. As stated in paragraph 3.3.2, the test team measured the I & Q channel BERs separately. Then, the I & Q channel results were averaged in order to generate the curves in Figure 6-10.

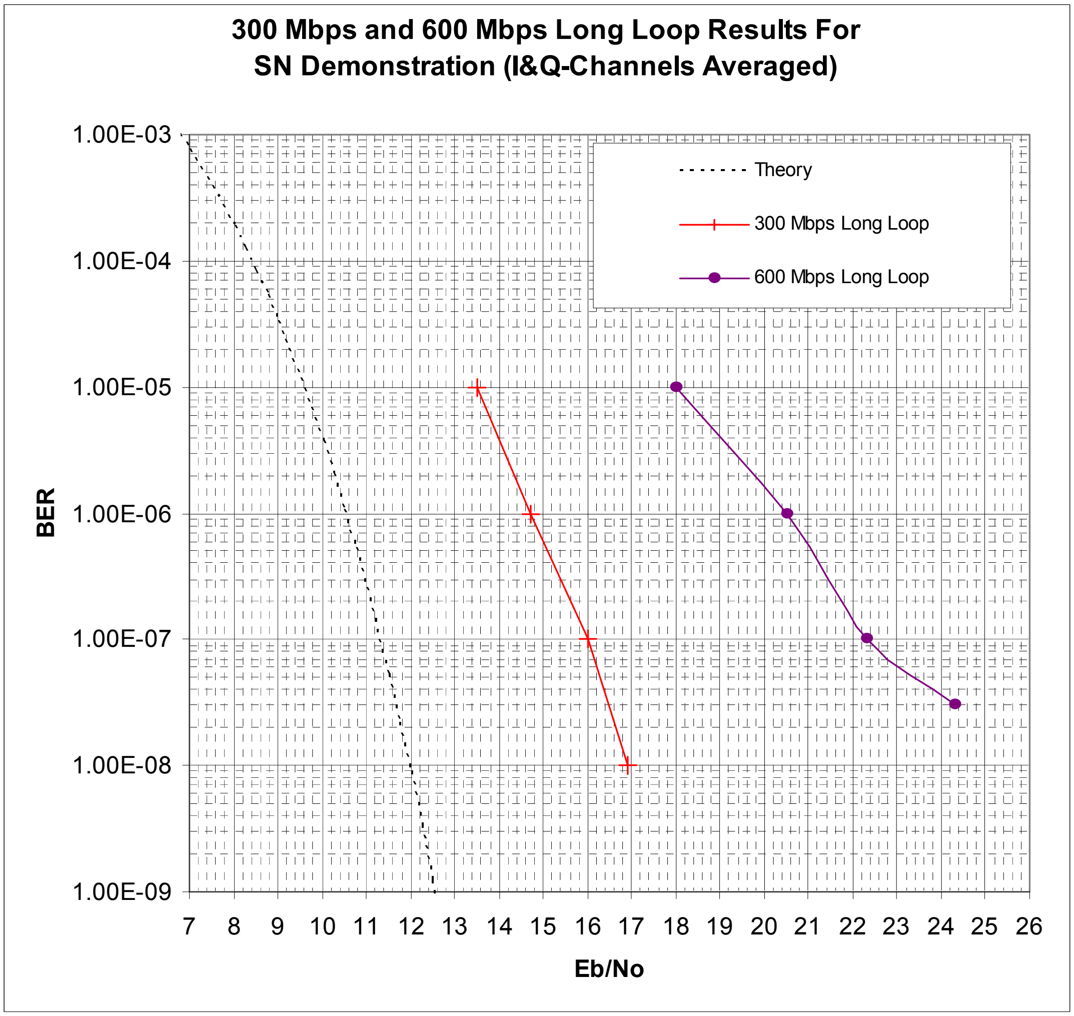

Figure 6-10. Long Loop 300 Mbps and 600 Mbps Eb/No Results

Table 6-7 lists the implementation loss results for the 300 Mbps and 600 Mbps tests. Implementation loss was calculated by subtracting the theoretical curve from the actual measured curve. In addition to the BER tests, the test team measured the carrier tracking threshold (Eb/No when carrier lock lost) and carrier acquisition threshold (Eb/No when carrier lock acquired). Table 6-8 lists the carrier lock loss and carrier lock acquisition results. The test team used the carrier lock indicator on the TSI receiver display to collect the carrier lock data.

Figure 6-11 and Figure 6-12 depict the spectrum analyzer plots for the 300 Mbps and 600 Mbps Long Loop tests.

Table 6-7. Long Loop 300 Mbps and 600 Mbps Implementation Loss Results

Data Rate	BER	Implementation Loss
300 Mbps	10^{-5}	3.9 dB
	10^{-7}	4.7 dB
600 Mbps	10^{-5}	8.4 dB
	10^{-7}	11.0 dB

Table 6-8. Long Loop 300 Mbps and 600 Mbps Carrier Lock Results

Data Rate	Eb/No At Carrier Lock Loss	C/No At Carrier Lock Loss	Eb/No At Carrier Lock Acquisition	C/No At Carrier Lock Acquisition
300 Mbps	1.9 dB	86.7 dB-Hz	1.9 dB	86.7 dB-Hz
600 Mbps	2.3 dB	90.1 dB-Hz	2.3 dB	90.1 dB-Hz

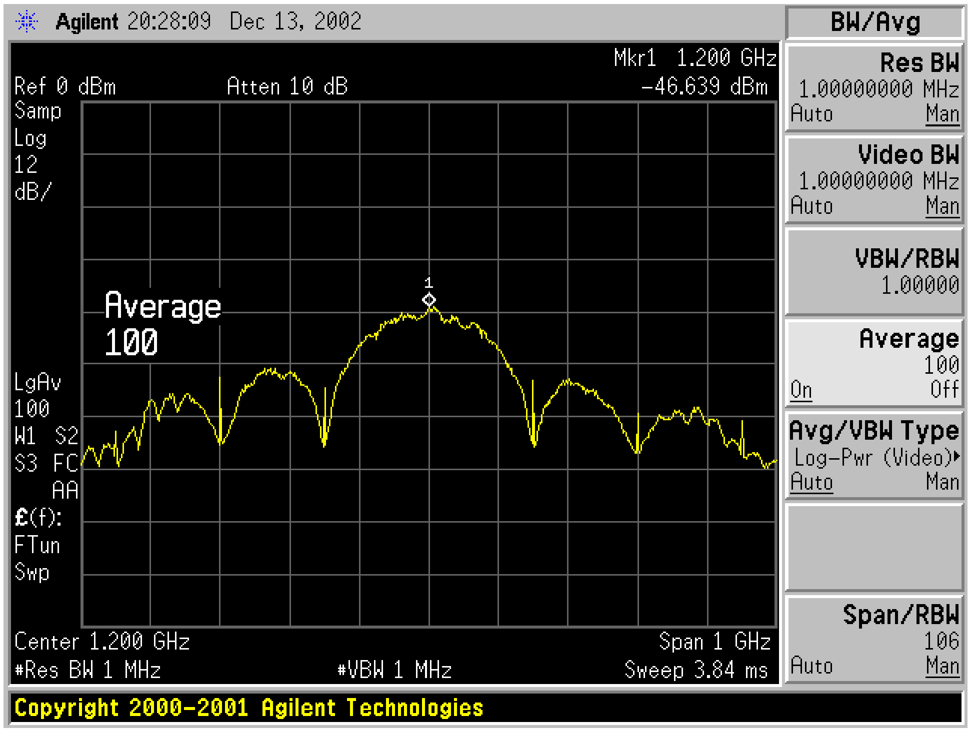

Figure 6-11. Spectrum Analyzer Plot, Long Loop Test, 300 Mbps

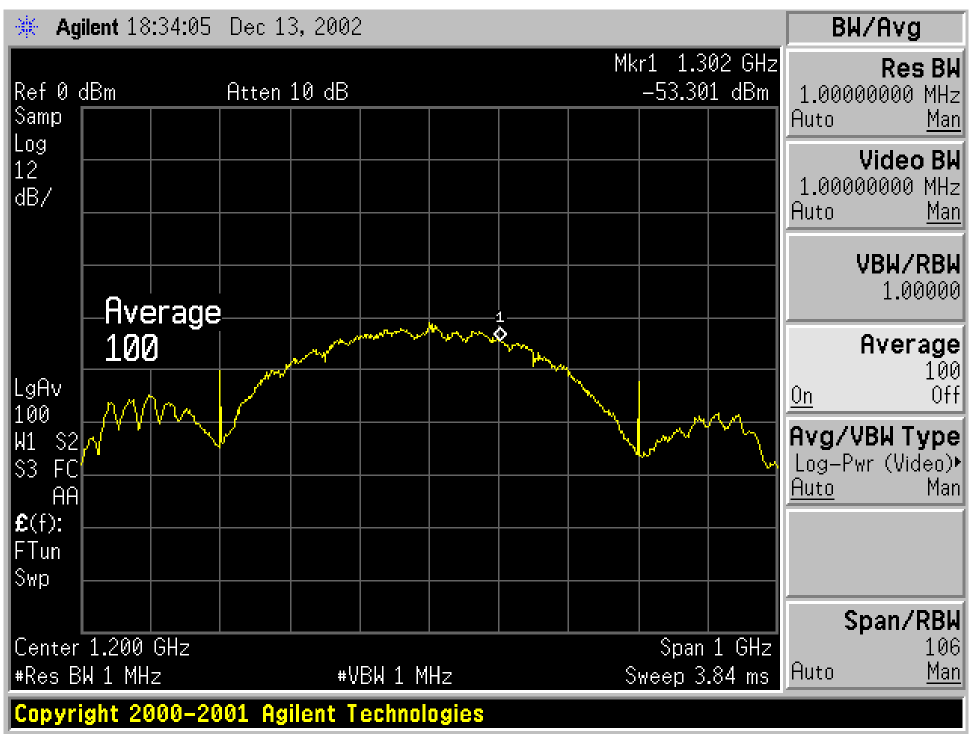

Figure 6-12. Spectrum Analyzer Plot, Long Loop Test, 600 Mbps

6.5 End-To-End Test

6.5.1 Test Results

This section describes the detailed results of the End-To-End tests at 300 Mbps and 600 Mbps. Figure 6-13 depicts the detailed End-To-End test configuration. This test included the TDRS-8 spacecraft, Demonstration Ka-Band Transmitting System, and SGLT-2 equipment. During the end-to-end tests only, a SHO was used to schedule the required SN KaSAR-Wideband (650 MHz Channel) IF Service equipment. The KaTP test team measured the E_b/N_0 values for BERs from 10^{-5} to 10^{-8}. The PN data generator provided data and clock signals to the TSI modulator. The spectrum analyzer was used to make C/No measurements. The test team calculated the Eb/No values from the C/No measurement data.

Table 6-9 summarizes the test equipment settings and configurations that were used for the 300 Mbps and 600 Mbps tests.

Table 6-9. End-To-End 300 Mbps & 600 Mbps Test Unit Settings/Configurations

Unit Name	300 Mbps Unit Settings/Configurations	600 Mbps Unit Settings/Configurations
PN Data Generator	300 Mbps Differential ECL output NRZ-L Data Format PRBS of 2^{23}-1	600 Mbps Differential ECL output NRZ-L Data Format PRBS of 2^{23}-1
TSI Modulator	300 Mbps Differential ECL input SQPSK, IF = 1.2 GHz Varied Output Power NRZ-L Data Format	600 Mbps Differential ECL input SQPSK, IF = 1.2 GHz Varied Output Power NRZ-L Data Format
Ka-Band Upconverter	25.6 GHz output frequency Attenuation = 20 dB	25.6 GHz output frequency Attenuation = 20 dB
Ka-Band HPA	80 Watts Output Power when TSI modulator set to -12 dBm. (Output lowered by lowering TSI modulator output power)	80 Watts Output Power when TSI modulator set to -12 dBm. (Output lowered by lowering TSI modulator output power)
TSI Receiver	150 Mbps on each Channel Differential ECL output QPSK, NRZ-L Data Format	300 Mbps on each Channel Differential ECL output QPSK, NRZ-L Data Format
Bit Error Rate Test Set	150 Mbps (Measured I&Q receiver channels separately) Differential ECL input NRZ-L Data Format PRBS of 2^{23}-1	300 Mbps (Measured I&Q receiver channels separately) Differential ECL input NRZ-L Data Format PRBS of 2^{23}-1
Spectrum Analyzer	Center Frequency = 1.2 GHz Resolution Bandwidth = 1.0 MHz	Center Frequency = 1.2 GHz Resolution Bandwidth = 1.0 MHz
650 MHz Equalizer (B chain)	Normal Mode Primary Waveguide Input	Normal Mode Primary Waveguide Input

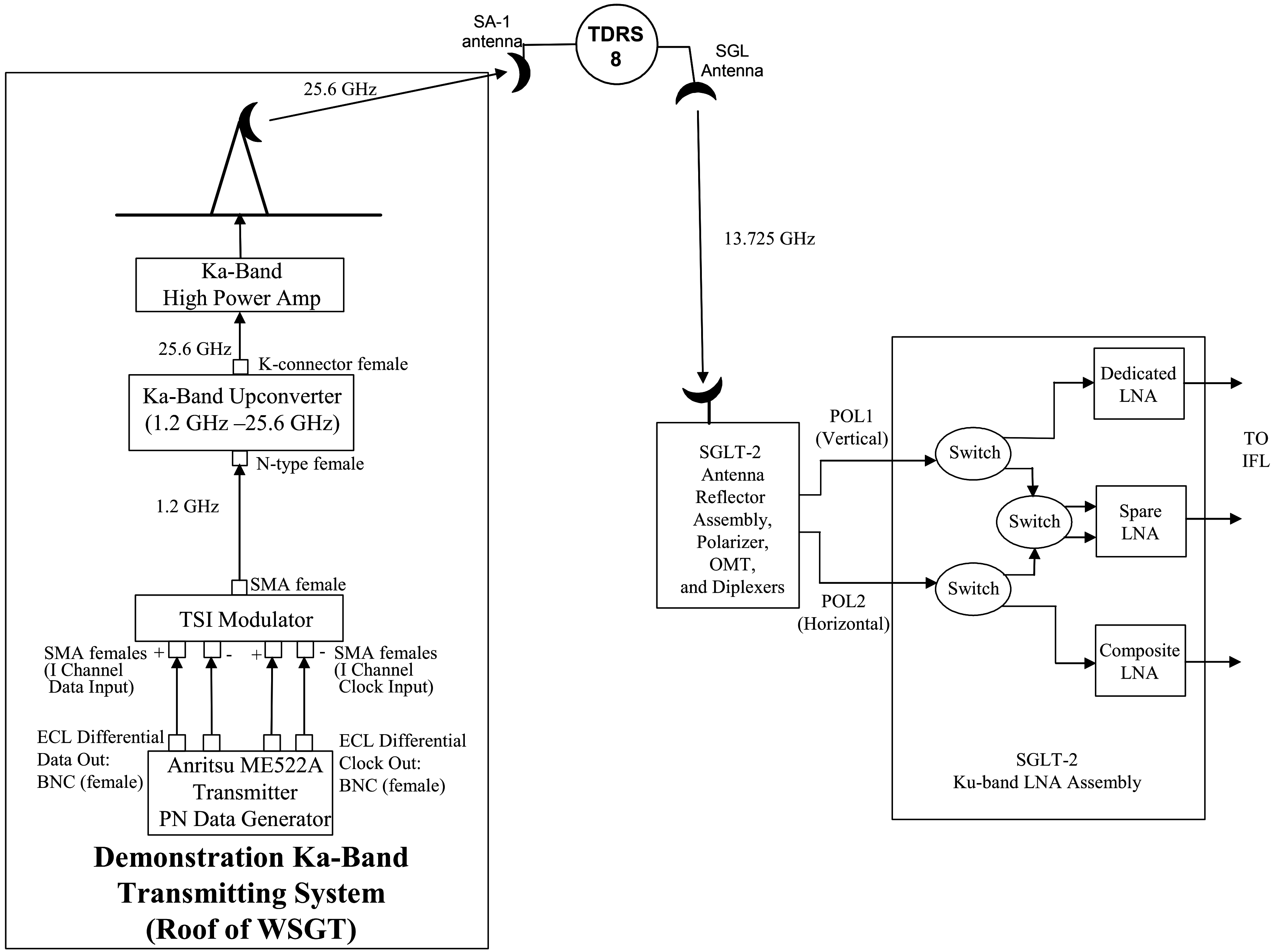

Figure 6-13. End-To-End Test Configuration (Sheet 1 of 3)

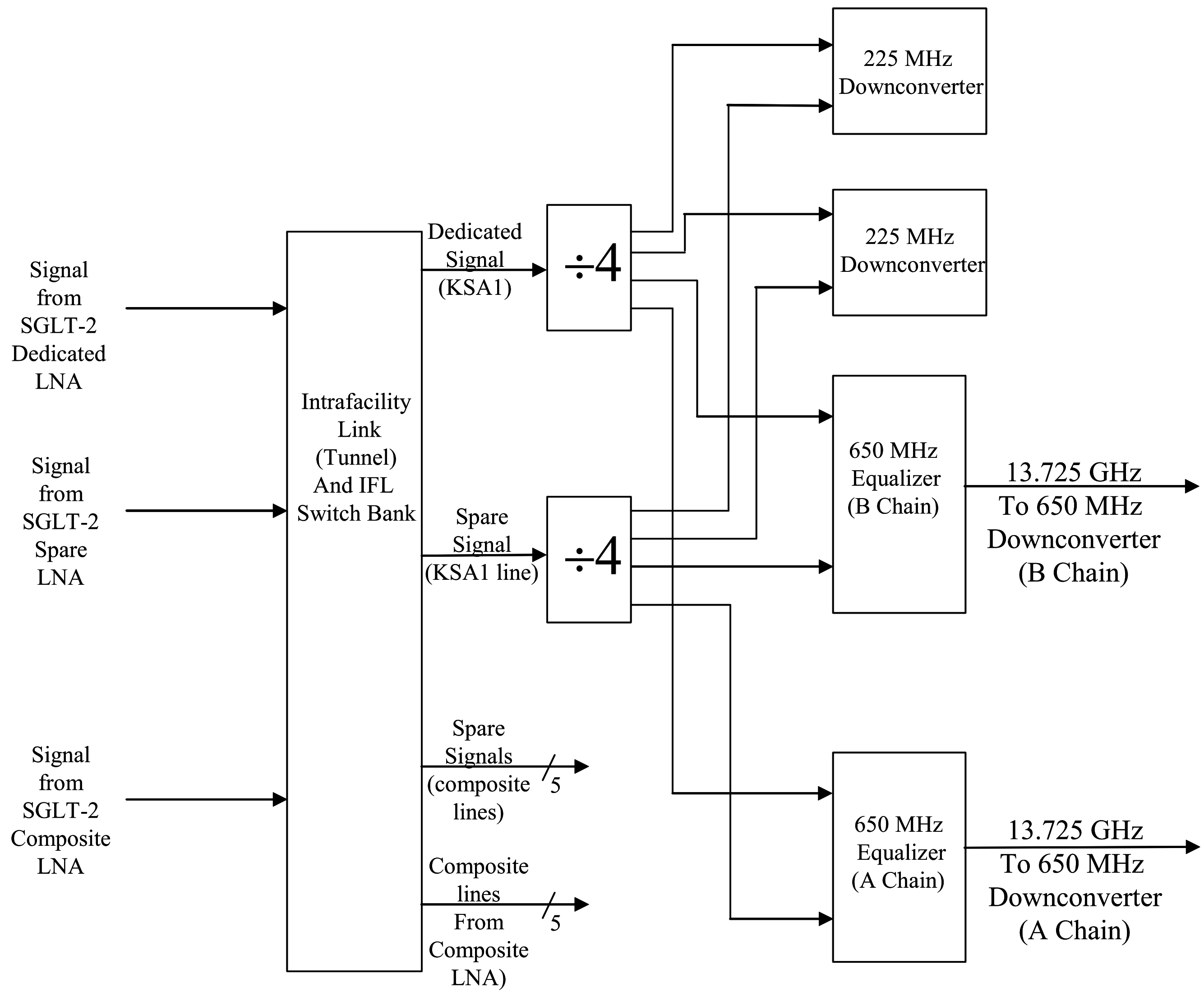

Figure 6-13. End-To-End Test Configuration (Sheet 2 of 3)

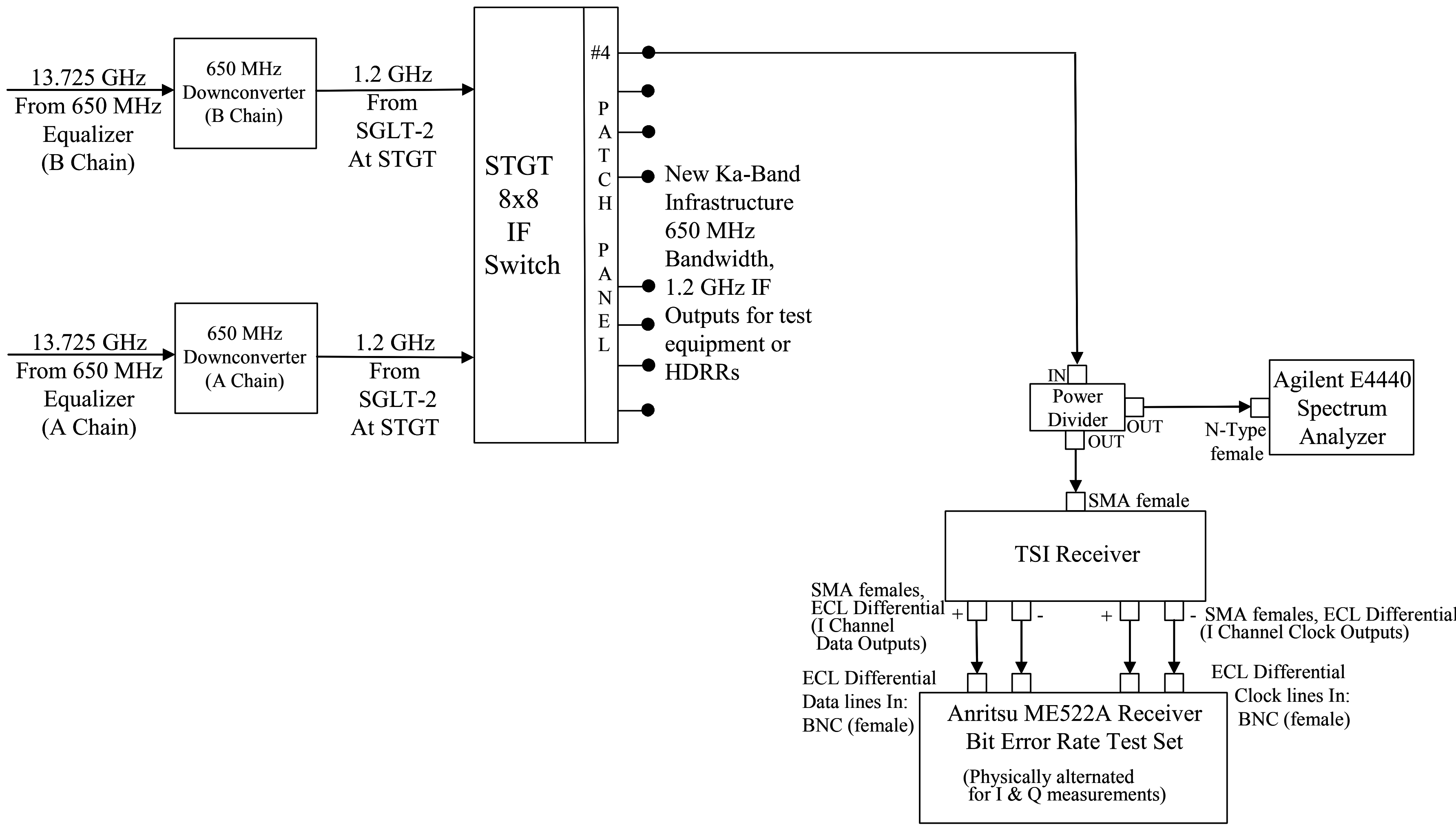

Figure 6-13. End-To-End Test Configuration (Sheet 3 of 3)

Figure 6-14 depicts the 300 Mbps and 600 Mbps Eb/No results for the End-To-End tests. As stated in paragraph 3.3.2, the test team measured the I & Q channel BERs separately. Then, the I & Q channels were averaged in order to generate the curves in Figure 6-14.

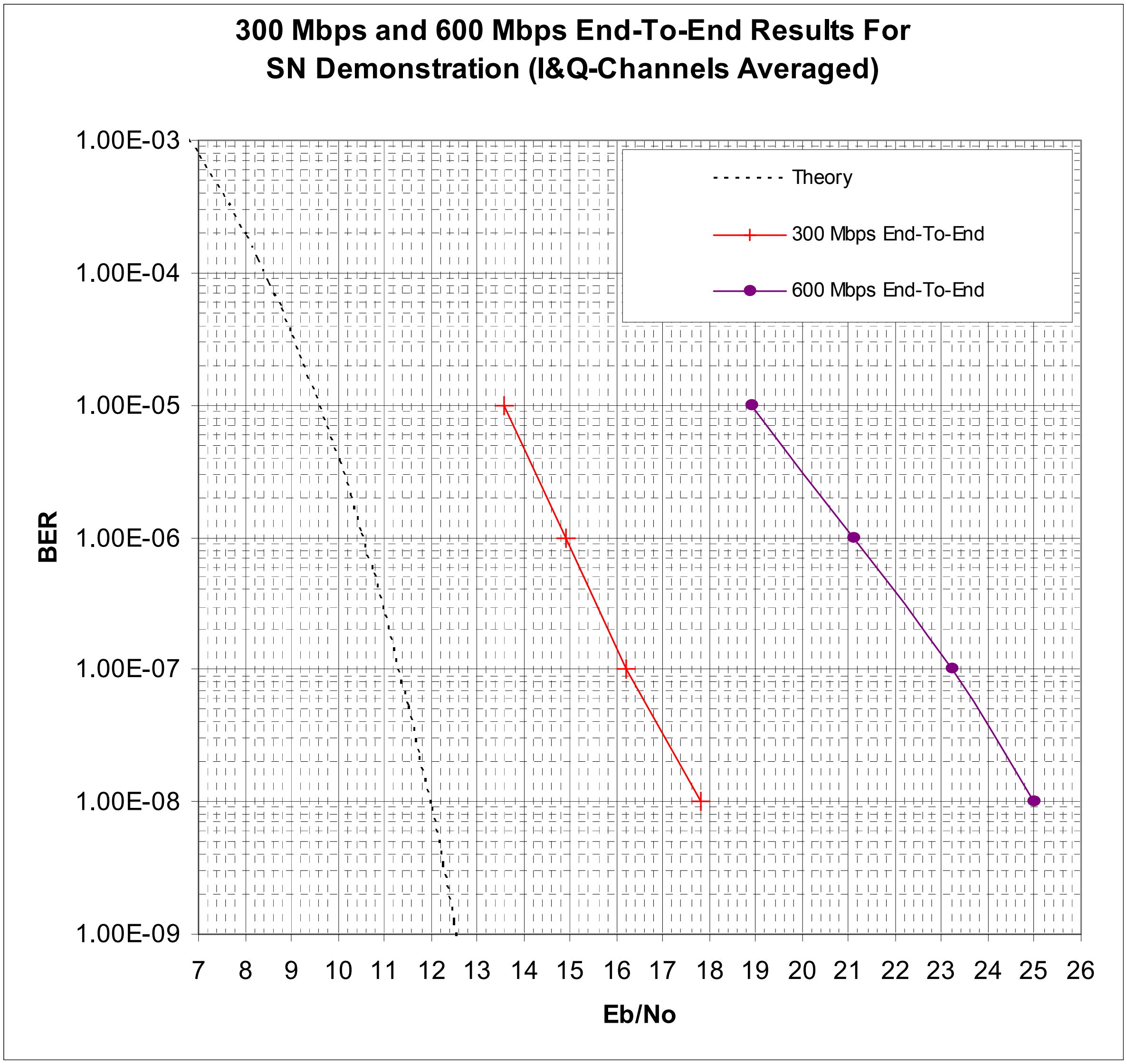

Figure 6-14. End-To-End 300 Mbps and 600 Mbps Eb/No Results

Table 6-10 lists the implementation loss results that were measured for the 300 Mbps and 600 Mbps tests. Table 6-10 also contains the predicted implementation loss values that were calculated from SPW end-to-end link simulations. Implementation loss was calculated by subtracting the theoretical curve from the actual measured curve or the curve obtained from SPW simulations. The SPW end-to-end simulation had the following inputs:

a. Spacecraft Transmitter: Ka-band User specification (reference [f]), except WFF Ka-band upconverter frequency response measurement data was used to replace the frequency response values in reference [f].
b. TDRS 650 MHz channel. TDRS-8 Frequency Response measurement data.
c. SGLT-2 Ground Terminal and KaTP Infrastructure: SRD specification values only.
d. Receive System: 4 dB implementation loss receiver.

In addition to the BER tests, the test team measured the carrier tracking threshold (Eb/No when carrier lock lost) and carrier acquisition threshold (Eb/No when carrier lock acquired). Table 6-11 lists the carrier lock loss and carrier lock acquisition results. The test team used the carrier lock indicator on the TSI receiver display to collect the carrier lock data.

Figure 6-15 and Figure 6-16 depict the spectrum analyzer plots for the 300 Mbps and 600 Mbps End-To-End tests.

Table 6-10. End-To-End 300 Mbps and 600 Mbps Implementation Loss Results

Data Rate	BER	Measured Implementation Loss	Predicted Implementation Loss
300 Mbps	10^{-5}	4.0 dB	Not Available
	10^{-7}	4.9 dB	Not Available
600 Mbps	10^{-5}	9.3 dB	9.8 dB
	10^{-7}	11.9 dB	13.6 dB

Table 6-11. End-To-End 300 Mbps and 600 Mbps Carrier Lock Results

Data Rate	Eb/No At Carrier Lock Loss	C/No At Carrier Lock Loss	Eb/No At Carrier Lock Acquisition	C/No At Carrier Lock Acquisition
300 Mbps	1.9 dB	86.7 dB-Hz	1.9 dB	86.7 dB-Hz
600 Mbps	2.7 dB	90.5 dB-Hz	3.5 dB	91.3 dB-Hz

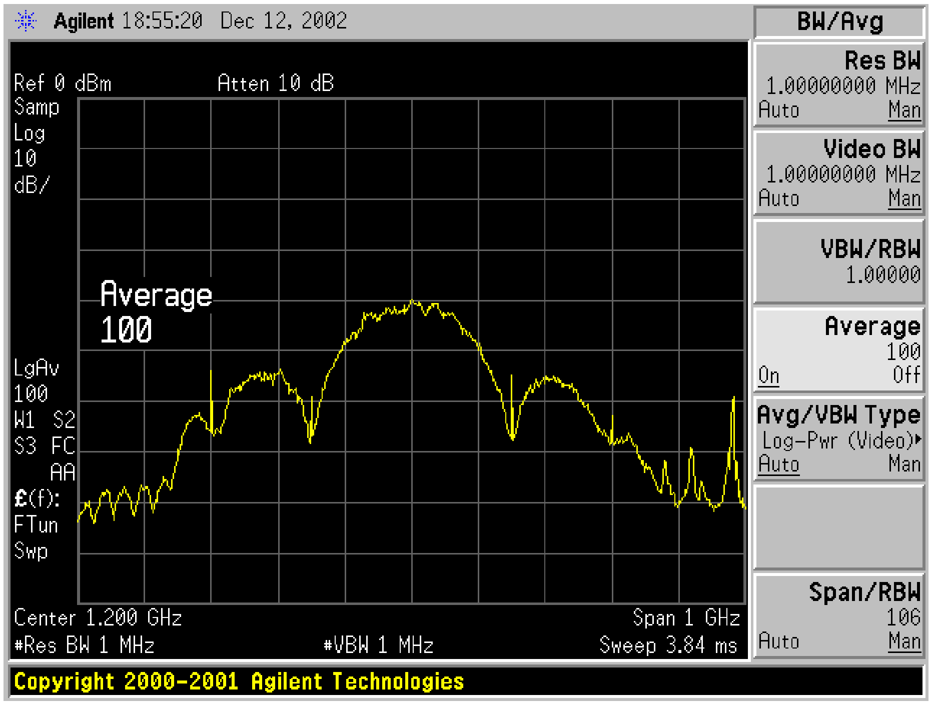

Figure 6-15. Spectrum Analyzer Plot, End-To-End Test, 300 Mbps

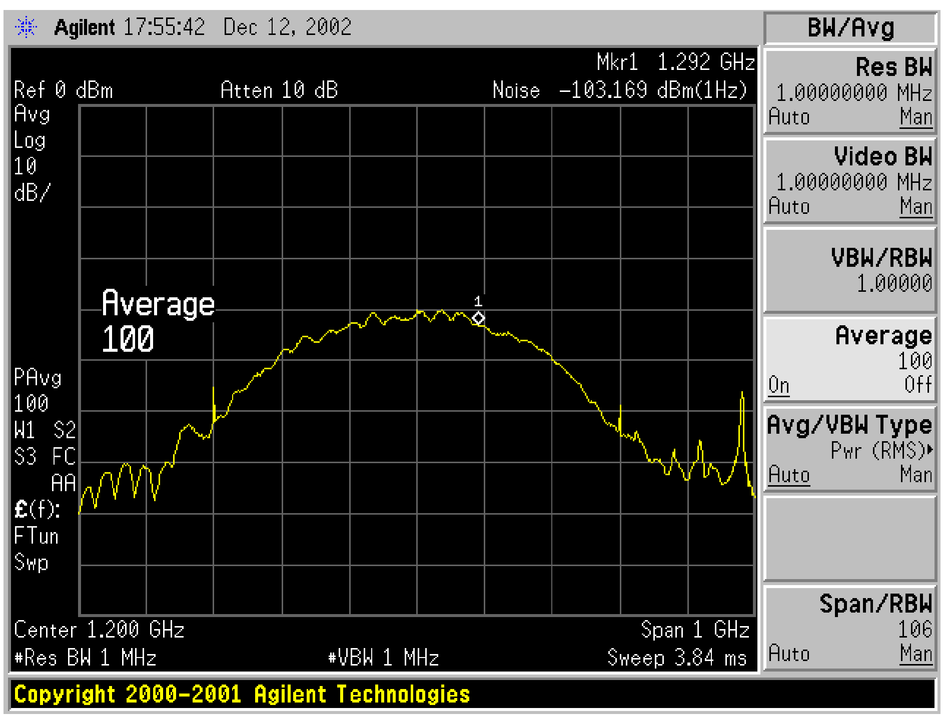

Figure 6-16. Spectrum Analyzer Plot, End-To-End Test, 600 Mbps

6.5.2 High Implementation Loss Explanation and Reduction Recommendation

Both the predicted and measured end-to-end 600 Mbps implementation loss are relatively high values (e.g., 9.3 dB measured for a 10^{-5} BER). The 9.3 dB implementation loss is significantly high for an operational SN service link. This large difference in implementation loss can be attributed to the following:

1. **Receiver implementation loss** – receiver-only implementation loss at 300 Mbps for the 10^{-5} BER point was measured to be 2.3 dB versus 4.0 dB at 600 Mbps. The commercial receiver used for the demonstration was designed to be data rate agile over a large range, and therefore may not have been optimized (in terms of performance) for the data rate of interest to NASA (600 Mbps). Additionally, it is expected that the receiver implementation loss would be largest near the top end of the supported data rate range (this receiver is specified to support data rates up to 600 Mbps) as the receiver phase and timing errors are likely to be largest at the highest data rates. During 600 Mbps tests at WFF in April 2003, WFF personnel discovered that the TSI receiver was not sampling at an optimum point in time during the bit period.

2. **Channel bandlimiting and other system distortions** – because the signal spectrum is twice as wide at 600 Mbps than 300 Mbps, the 600 Mbps spectrum will encounter additional attenuation at the band edges resulting in a larger implementation loss. Additionally, the wider 600 Mbps signal will likely encounter higher linear and nonlinear channel distortions than the more narrow 300 Mbps signal, again resulting in a larger implementation loss. For example, the phase nonlinearity over the center 300 MHz of the channel may be very flat, however, when considering the entire 650 MHz channel, the phase nonlinearity will be less flat.

3. **Combined effects** - the impact of some distortions on implementation loss may be greater when in combination with a receiver that is not optimized for a particular data rate. For example, transmitter bit jitter can have a greater impact when the bit synchronizer timing error is large (i.e., not tuned to a particular data rate) than when the timing error is small.

SPW simulations of the TDRSS KaSAR-wide channel have indicated that using a receiver with a small implementation loss (3.0 dB or less) will result in a much lower end-to-end system implementation loss. SPW simulations of the TDRSS KaSAR-wide channel have also indicated that using an adaptive baseband equalizer (ABBE) similar to the existing ABBE at WSC for the 225 MHz KSAR service, will result in lower implementation loss (up to 1.8 dB lower at a 10E-05 BER). Therefore, using an ABBE in addition to a modulator and receiver with a lower back-to-back 600 Mbps implementation loss would improve the end-to-end operational link performance. Also, improving the gain flatness and phase nonlinearity characteristics of the link is another end-to-end implementation loss reduction option for a 600 Mbps SN data link. WSC is presently procuring channel equalizers to improve the gain flatness of the WSC ground terminal.

6.6 Summary Of Results Including Minimum Prec Calculations

This section summarizes and compares the results from the Back-To-Back Loop tests, Medium Loop tests, Long Loop tests, and End-To-End Tests. Also, this section includes the predicted minimum Prec that a Ka-band customer spacecraft would need to provide at the TDRS-8 SA-1 antenna when transmitting 300 Mbps or 600 Mbps with the new IF Service and receiving with the TSI receiver.

Figure 6-17 depicts the 600 Mbps results for all of the test configurations. As expected, the implementation grew as more equipment was added to the test configuration.

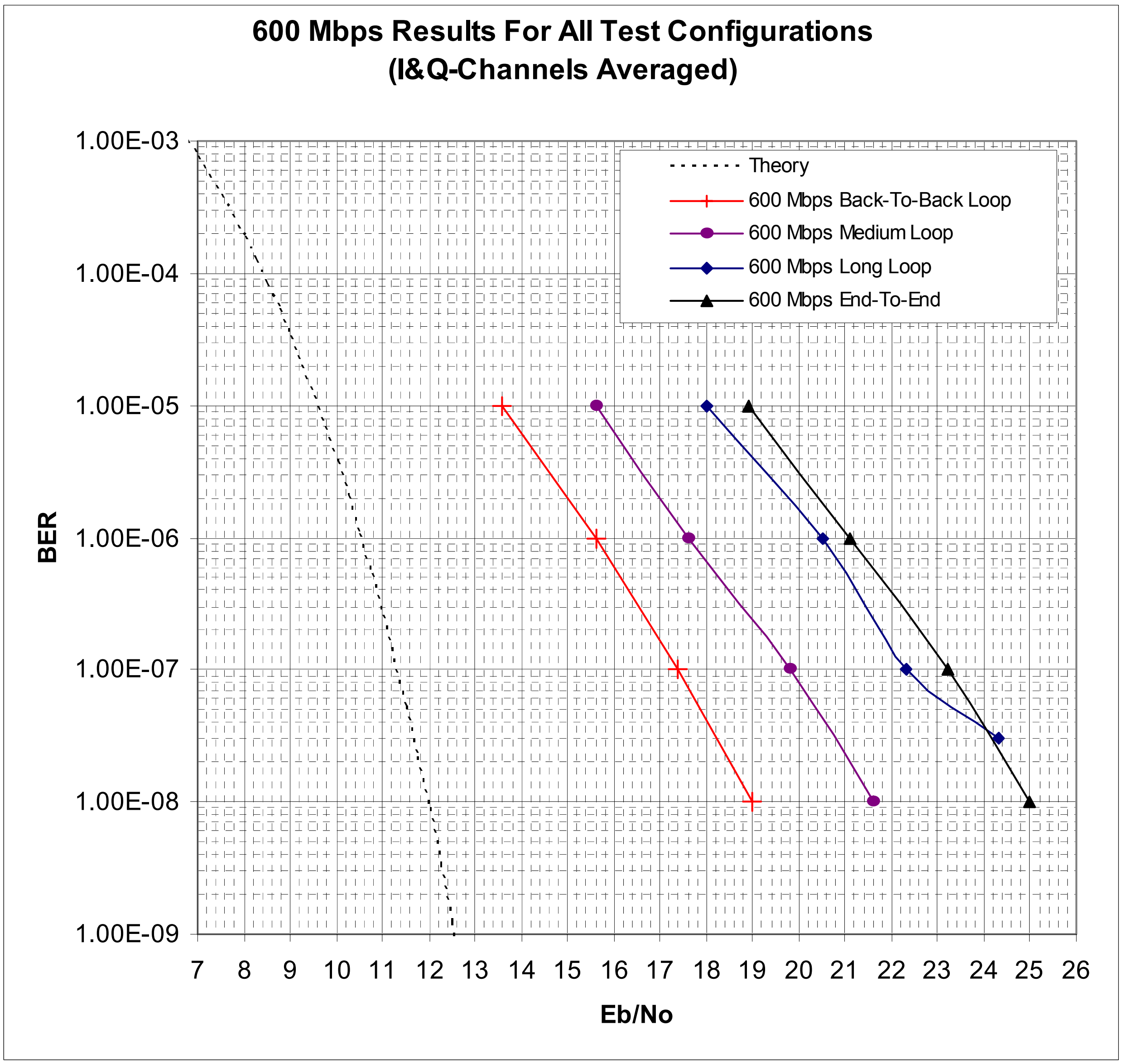

Figure 6-17. 600 Mbps Results For All Test Configurations

As expected, the long loop implementation loss and end-to-end implementation loss are similar. This was expected because the long loop test had units in its configuration that were not in the end-to-end tests. For example, the WSC Ku-Band test upconverter and 40 dB fixed attenuator were in the long loop test configuration, but they were not in the end-to-end test configuration. However, the goal for the long loop as well as the medium loop was to provide data in order to assess the effects of the Downconverter/IF Switch Subsystem distortions and the Waveguide/Equalizer Subsystem distortions on the overall link as best as possible with the available test equipment. That goal was achieved by collecting E_b/N_o curve data during the medium and long loop tests. Based on the E_b/N_o curves in Figure 6-17 that were produced during the various characterization tests (Back-To-Back, Medium Loop, Long Loop, and End-To-End), the test team successfully assessed and documented the effects of the Downconverter/IF Switch Subsystem and Waveguide/Equalizer Subsystem distortions on the overall link.

Table 6-12 lists the 300 Mbps and 600 Mbps implementation loss values.

Table 6-12. Summary of 300 Mbps And 600 Mbps Results For All Test Configurations

Test Configuration	BER	300 Mbps Measured Implementation Loss	600 Mbps Measured Implementation Loss
Back-To-Back Loop Test	10^{-5}	2.3 dB	4.0 dB
	10^{-7}	2.6 dB	6.1 dB
Medium Loop Test	10^{-5}	3.0 dB	6.0 dB
	10^{-7}	3.5 dB	8.5 dB
Long Loop Test	10^{-5}	3.9 dB	8.4 dB
	10^{-7}	4.7 dB	11.0 dB
End-To-End Test	10^{-5}	4.0 dB	9.3 dB
	10^{-7}	4.9 dB	11.9 dB

The KaTP test team calculated the predicted minimum Prec that a Ka-band customer spacecraft will need to provide at the TDRS-8 SA-1 antenna for a given data rate when using the TSI receiver. See reference [e], Appendix A for a more detailed discussion on Prec. The Prec values were calculated by using the end-to-end E_b/N_0 test results and measured implementation loss values. The predicted minimum Prec for the 600 Mbps End-To-End Test, a 10^{-5} BER, and TSI receiver is -148.46 dBWi. The predicted minimum Prec for the 300 Mbps End-To-End Test, a 10^{-5} BER, and the TSI receiver is -157.6 dBWi.

Specifically, the test team calculated the Prec by replacing the predicted implementation loss value in the SN predicted link budget with the measured implementation loss. Figure 6-18 depicts the predicted 600 Mbps link budget with the measured 10^{-5} BER implementation loss for 600 Mbps. The measured implementation loss, 9.3 dB, was entered into Line 34 on Figure 6-18. Then the "Demonstration System RF Power, Watts" (Line #1 on Figure 6-18) was changed until the system margin (Line 37) became 0 dB. Parameters like the TDRS-8 SA-1 antenna G/T, the WSC G/T, and Demonstration Transmitting System Antenna Losses were not changed. A Prec of -148.46 dBWi (Line 10 on Figure 6-18) occurs when the system margin is 0 dB.

One should note that the "Demonstration System RF Power" required to achieve a 0 dB system margin in the predicted link budget is 104.9 Watts even though 80 Watts was the maximum available power during the SN Demonstration. Also, the test team only used 20 Watts to actually achieve a 10^{-5} BER during the SN Demonstration. The reason for the power discrepancy (more than 7 dB) is that Figure 6-18 yields a predicted minimum Prec based on only specification values for some link budget parameters. Therefore, based on the SN Demonstration, some parameters in the link budget are too conservative. For example, the actual TDRS-8 SA-1 G/T during the demonstration was probably higher than 27.5 dB/°K (Line 11 on Figure 6-18). Also, the Demonstration System Passive losses were probably lower than 2.5 dB (Line 4 on Figure 6-18).

Therefore, if the actual values that existed during the demonstration for all items in the link budget were available, then Figure 6-18 would yield a lower minimum Prec value. Also, if an improved receiver is used, then the implementation loss would change because the minimum Prec is also a function of the receiver performance in the system. Therefore, the Prec calculated from this demonstration data should not be placed in the SN Users' Guide. The KaTP test team recommends that after procuring the operational receiver system for the 650 MHz channel service, NASA should conduct follow-on testing and analysis activities in order to determine minimum Prec values for publication in the SN Users' Guide.

Line #	Budget Parameter	600 Mbps No Eq	Notes
1	Demo. System RF Power, Watts	104.90	Power in link budget required for 0 dB link Margin for 1.0E-05 BER (actual power used to close link was less)
2	Demo. System RF Power, dBW	20.21	10*log(RF Power)
3	Demo. System Antenna Gain, dBi	47.60	Based on 1.2 meter diameter and 55% efficiency
4	Demo. System Passive Loss, dB	2.50	Additional passive losses derived from spec sheet provided by WSC
5	Demo. System EIRP, dBW	65.31	Function of input power from line #1
6	Path loss, dB	212.81	Freq. = 25,600 MHz, Range = 40727.0 km
7	Polarization loss, dB	0.10	Engineering Estimate
8	Atmospheric loss, dB	0.86	ITU Model, TDRS-8 at 171° with 7° inclination (1,2)
9	Rain attenuation, dB	0.00	Assumes no rain during demo
10	Power received, dBWi	-148.46	
11	Relay satellite G/T, dB/K	27.50	Worst case autotrack G/T, TDRS-8 Test Data
12	Boltzmann's constant, dBW/Hz-K	-228.60	10log(Boltzmann's Constant)
13	SGL C/No (total), dB-Hz	107.64	
14	Bandwidth, dB-Hz	88.13	10log(650 MHz)
15	**SGL C/N (minimum), dB**	**19.51**	
16	TDRS EIRP, dBW	54.00	Maximum Specified Value; 52 dBW nominal
17	Space loss, dB	207.40	Freq. = 13.725 GHz, Range = 40727.0 km
18	Pointing loss, dB	0.00	TPID (3)
19	Polarization loss, dB	0.03	TPID (3)
20	Atmospheric loss, dB	0.25	TPID (3)
21	Rain attenuation, dB	0.00	Assumes no rain during demo
22	Power received at WSC, dBWi	-153.7	
23	WSC G/T, dB/K	40.30	From SY-011
24	Cross polarization degradation, dB	1.48	Worst Case from TDRS-HIJ TPID
25	Boltzmann's constant, dBW/Hz-K	-228.60	10log(Boltzmann's Constant)
26	SGL C/No, dB-Hz	113.74	
27	Bandwidth, dB-Hz	88.13	10log(650 MHz)
28	**SGL C/N at WSC, dB**	**25.61**	
29	**Total C/N at WSC, dB**	**18.55**	
30	Bandwidth, dB-Hz	88.13	10log(650 MHz)
31	**C/No at WSC, dB-Hz**	**106.68**	
32	Bit rate, dB-b/sec	87.78	10*log (Data Rate)
33	Eb/No (into demodulator), dB	18.90	
34	Total Implementation Losses, dB	9.30	Based on SN demonstration End-To-End results for 10e-5 BER. (See Table 6-12)
35	Net Eb/No, dB	9.60	
36	Required Eb/No, dB	9.60	QPSK uncoded, BER 10e-5
37	**System Margin, dB**	**0.00**	
38	Required Margin, dB	0.00	
39	**Margin**	**0.00**	

(1) Assumes the TDRS-8 Spacecraft is at its southern-most point in its orbit. This results in a worst case scenario such that the TDRS-8 is farthest from the WSC.
(2) Assumes a 25.6 GHz KaSAR SSL frequency and 15° C.
(3) TDRSS Telecommunication Performance and Interface Document (TPID),SE-09, 27 January 1989.

Figure 6-18. SN Predicted 600 Mbps Link Budget (10^{-5} BER)

Section 7. Anomalies During SN Demonstration

This section discusses the following two anomalies that were observed during the SN Demonstration:

1. Link performance variations as a function of KaSAR-Wideband IF Service center frequency
2. Interference on composite space-ground link (SGL) channel

7.1 Link Performance Variations

Section 6 of this report provides the SN Demonstration results for the KaSAR-wide service operating at a 25.6 GHz center frequency. The KaTP test team tested other center frequencies during the SN Demonstrations, but the performance on those frequencies was poor and not included in Section 6. For center frequencies higher than 25.6 GHz, the test team could not close the 600 Mbps link for BERs of 10^{-5} or better. The KaTP test team is planning to collect additional test data at several center frequencies above 25.6 GHz in order to more fully characterize this problem.

The new WSC Ka-band infrastructure is not considered the cause of this anomaly. The Ka-band return signal is frequency translated to a fixed Ku-band frequency on the TDRS spacecraft, therefore the WSC equipment will always process a signal at the same center frequency regardless of the Ka-band return center frequency.

Additional characterization testing should allow WSC to determine the source or sources of the performance anomaly at higher Ka-band frequencies.

WSC will conduct characterization testing on the Demonstration Ka-Band Transmitting System. Phase and gain response as a function of center frequency will indicate whether this portion of the end-to-end demonstration link was a significant contributor to the poor link performance. Also, the test team will use an improved technique for sampling a bit when using the TSI receiver. The improved technique should reduce the receiver implementation loss at 600 Mbps.

Also, during the characterization testing, WSC will investigate the frequency response of the TDRS-8 650 MHz wideband channel over the specified 25.25 – 27.5 GHz bandwidth. Initially, this can be accomplished by transmitting a noise-loaded signal at various center frequencies and viewing the received spectrum on a spectrum analyzer. The KaTP test team is also investigating the use of special test equipment that may allow phase non-linearity measurements of a wideband satellite channel. Further end-to-end link characterizations will also be performed using a modulated 600 Mbps signal.

7.2 Interference On Composite Space-Ground Link Channel

7.2.1 Interference Issue Details

During a portion of the SN demonstration, interference occurred on the TDRS-8 composite space-ground link (SGL) channel that degraded the SGLT-2 SGL antenna autotrack performance which, in turn, degraded the effective G/T of the SGLT-2 SGL antenna. This degraded autotrack performance was observed when radiating a Ka-band continuous wave (CW) test signal at a Space Network Interoperability Panel (SNIP) frequency from the Demonstration Ka-Band Transmitting System. The recent KaTP upgrades at WSC for the 650 MHz-wide channel were designed to support the SNIP frequency plan rather than the TDRS-HIJ frequency plan. The Ka-band CW signal was downconverted by the TDRS-8 spacecraft to 13.725 GHz for the SGL downlink. In addition, all of the SNIP Ka-band center frequencies for the new KaSAR-wideband IF Service translate to the TDRS-HIJ unique SGL telemetry center frequency (13.725 GHz), but on the opposite polarization. It is believed that cross-polarization leakage from the CW signal on the dedicated SGL downlink interfered with the SGL telemetry signal at 13.725 GHz on the composite downlink. Interference to the telemetry signal can impact SGL autotrack performance because the TDRS telemetry signal is AM-modulated on the ground with the SGL autotrack error signals. It should be noted that strong CW signals may occur on the SGL dedicated downlink during normal operations because link characterization and C/No measurements are sometimes best collected with CW signals.

The TDRS-HIJ unique telemetry frequency (13.725 GHz) is used for co-locating a TDRS-HIJ spacecraft with a TDRS F1-F7 spacecraft. Use of the standard TDRS telemetry frequency (13.731 GHz) would preclude interference, but would not allow TDRS spacecraft co-location. Figure 7-1 depicts the SNIP frequency plans and the TDRS-HIJ frequency plans for the 225 MHz and 650 MHz channels.

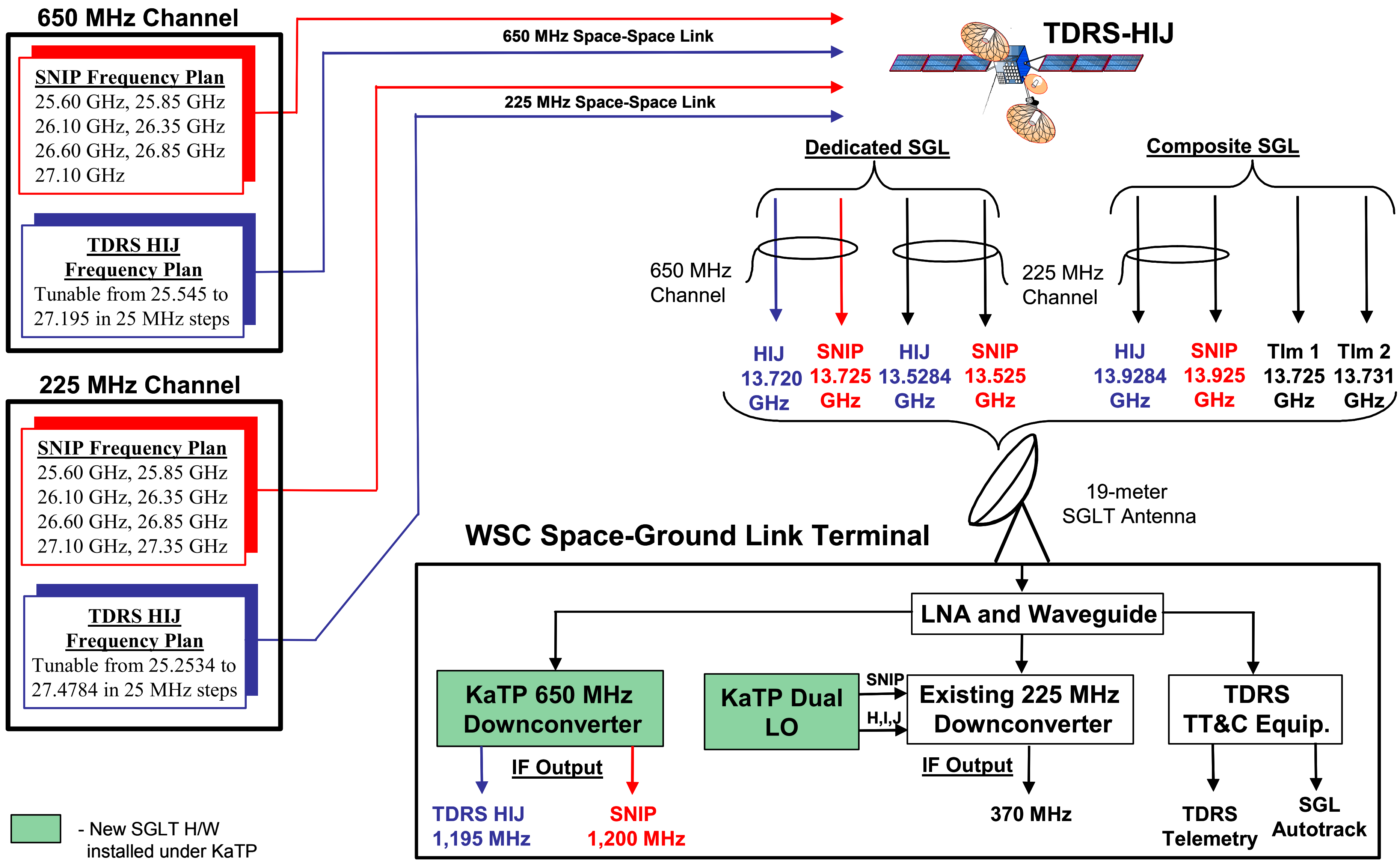

Figure 7-1. KaSAR Frequency Plan

7.2.2 Space Network Interoperability Panel Background

The SNIP recommendation was established in June 1995 to promote compatibility of Ka-Band low Earth Orbit (LEO) spacecraft with NASA, European Space Agency (ESA), and National Space Development Agency of Japan (NASDA) data relay satellite systems. The SNIP recommendation states that each data relay satellite system be able to receive return space-to-space signals at the specified Ka-band SNIP frequencies and with bandwidths up to 225 MHz.

NASA did not require the TDRS-HIJ development contractor to provide spacecraft or ground modifications to support the SNIP frequency plan.

KaTP required SNIP Ka-Band frequency compatibility on both the TDRS-HIJ 225 MHz-wide channel and TDRS-HIJ 650 MHz-wide channel. KaTP implemented their requirements as follows:

a. Installed Dual local oscillators (LOs) in the existing 225 MHz downconverters to allow both SNIP and TDRS-HIJ Ka-band frequency plan operation.

b. Procured new 650 MHz downconverters with a single LO to allow only SNIP frequency plan operation on the 650 MHz channel. TDRS-HIJ frequency plan support was not implemented on the 650 MHz channel.

NASA support of the SNIP frequency plan on the 225 MHz-wide Ka-band channel provides compliance with the SNIP recommendation. The SNIP recommendation does not require NASA to support the SNIP frequency plan on the 650 MHz-wide channel.

7.2.3 CW Interference Resolution

NASA's plan to mitigate the SGL interference is to support only the TDRS-HIJ frequency plan for the KaSAR-wide service. Use of the TDRS-HIJ frequency plan will result in a SGL center frequency of 13.720 GHz rather than 13.725 GHz when using the SNIP frequency plan. However, the SN will still comply with the SNIP recommendation because it will support SNIP frequencies on the 225 MHz-wide channel.

A 13.720 GHz SGL center frequency and the TDRS-HIJ frequency plan can be supported if the 650 MHz downconverters are modified by replacing their local oscillators. WSC has begun the process for the 650 MHz downconverter modifications. The modifications will allow the SN to maintain a 1200 MHz IF for the KaSAR-wide (650 MHz channel) IF Service and will eliminate the possibility of SGL self-interference during CW signal transmissions.

Section 8. Demonstration Results With Code 564 Receiver

Limited TDRS-8 spacecraft time was available for Code 564 receiver testing. Therefore, the KaTP test team only obtained one data point with the Code 564 receiver in the end-to-end test configuration. The End-To-End test configuration for the Code 564 receiver was almost identical to the TSI receiver End-To-End test configuration that is depicted in Figure 6-13. The only difference from the TSI receiver tests was that the TSI modulator was set to QPSK rather than to SQPSK.

This test demonstrated that the Code 564 receiver can support 600 Mbps through the SN. The Ka-band Demonstration Transmitting System used the TSI modulator which was configured for dual channel, uncoded QPSK modulation with a NRZ-L data format on each channel. The Code 564 receiver was configured for QPSK and individual I and Q channel BER measurements were performed.

The KaTP test team obtained one data point at a C/No at the receiver of 111 dB. For 600 Mbps, a 111 dB C/No provides an Eb/No of 23.2 dB. The measured BER (I & Q Channels averaged) at an Eb/No of 23.2 dB, was 1.2E-06. Thus, the implementation loss at that BER was 12.7 dB. The implementation loss was higher than the implementation loss measured during the end-to-end tests with the TSI receiver. However, the Code 564 receiver test was performed using QPSK modulation which typically incurs higher losses through non-linear satellite channels than SQPSK. QPSK modulation was used for this test because the Code 564 receiver can not support SQPSK at 600 Mbps.

If time and resources are available in the future, then the KaTP project will conduct more Code 564 receiver tests in order to fully characterize the Code 564 receiver SN performance.

Section 9. Legacy 225 MHz Narrowband Channel Tests

After the 650 MHz-wide channel tests were completed, the KaTP test team collected legacy test data at 300 Mbps on the 225 MHz-wide channel for the following test scenarios:

a. Ka-Band, 300 Mbps, TDRS-8 225 MHz-wide Channel, 25.6 GHz, SQPSK
b. Ku-Band, 300 Mbps, TDRS-8 225 MHz-wide Channel, SQPSK

For the Ka-Band test, the TSI modulator and Ka-band upconverter were used to generate the KaSAR test signal. The test team used the operational WSC 370 MHz IF High Data Rate Receiver (HDRR) receiver. For the Ku-Band test, the existing Ku-Band SGLT End-To-End Test (EET) System was used in conjunction with the WSC HDRR.

The limited TDRS-8 spacecraft time available for the legacy tests resulted in questionable Ka-Band test data. Therefore, additional testing is planned for the TDRS-HIJ 225 MHz-wide channel using the HDRR.

Figure 9-1 depicts the 300 Mbps results for both legacy tests.

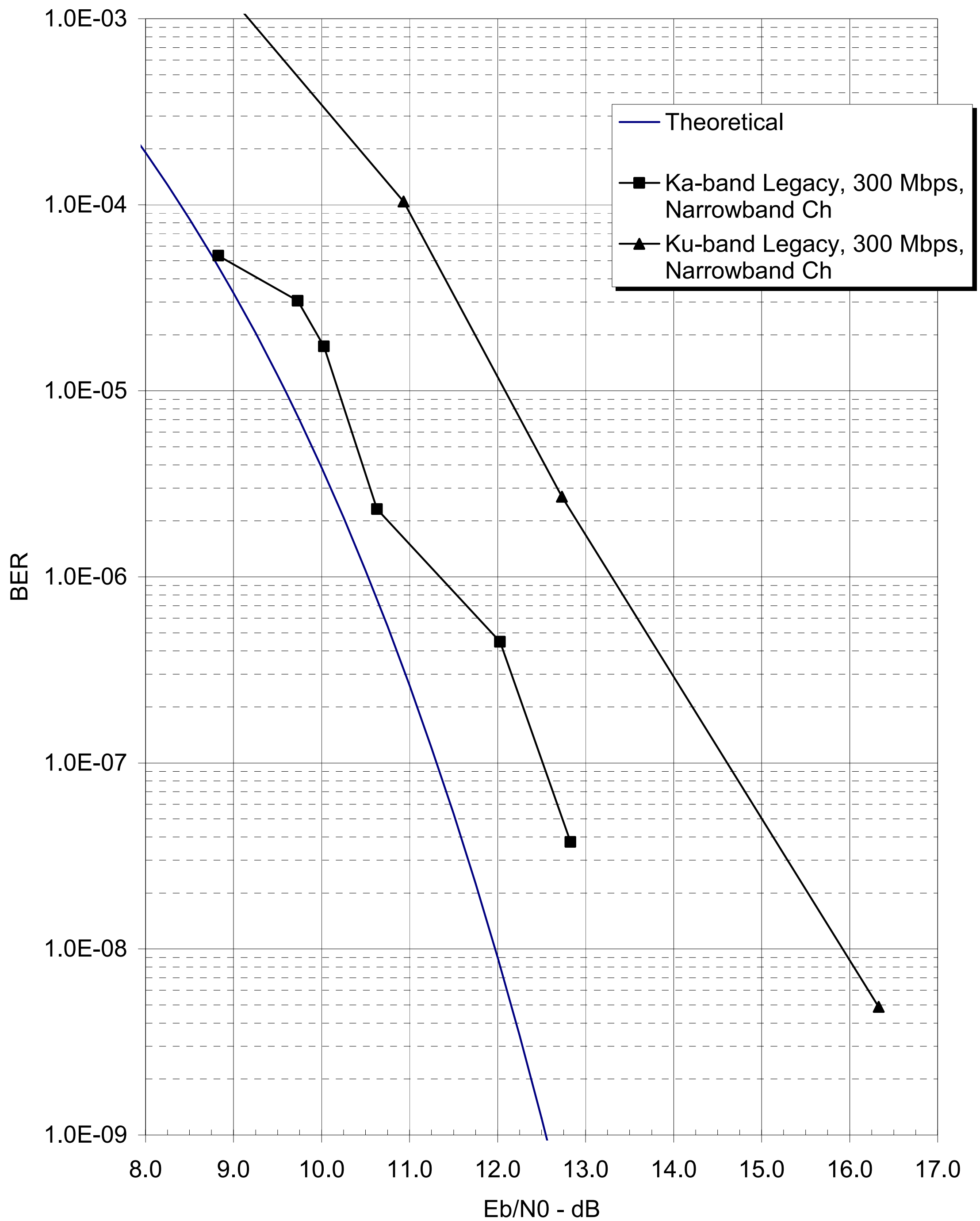

Figure 9-1. 300 Mbps Legacy Test Results

Section 10. Conclusions

1. The KaTP project successfully demonstrated that the SN can support uncoded 600 Mbps using the TDRS-8 650 MHz-wide channel and the WSC infrastructure upgrades.

2. Based on the E_b/N_o curves in Figure 6-17 that were produced during the various characterization tests (Back-To-Back, Medium Loop, Long Loop, and End-To-End), the test team successfully assessed and documented the effects of the Downconverter/IF Switch Subsystem and Waveguide/Equalizer Subsystem distortions on the overall link.

3. The implementation loss increases as BER decreases:

   a. For 600 Mbps and a 10^{-5} BER, the total end-to-end implementation loss was 9.3 dB.
   b. For 600 Mbps and a 10^{-7} BER, the total end-to-end implementation loss was 11.9 dB.

4. Both the predicted and measured end-to-end 600 Mbps implementation loss values are relatively high values (e.g., 9.3 dB measured for a 10^{-5} BER). The 9.3 dB implementation loss is significantly high for an operational SN service link. As noted in paragraph 6.5.2, the impact of some distortions on implementation loss may be greater when in combination with a receiver that is not optimized for a particular data rate. During 600 Mbps tests at WFF in April 2003, WFF personnel discovered that the TSI receiver was not sampling at an optimum point in time during the bit period. Also, improving the gain flatness and phase nonlinearity characteristics of the link is another end-to-end implementation loss reduction option for a 600 Mbps SN data link. WSC is presently procuring channel equalizers to improve the gain flatness of the WSC ground terminal.

5. The 650 MHz-wide channel link performance varied as a function of the Ka-band center frequency as described in section 7.1. WSC is planning to conduct follow-on characterization testing to more fully characterize that frequency dependent performance. The follow-on characterization testing will include the following:

   a. TDRS-HIJ 650 MHz-wide channel performance as a function of center frequency testing which will include 600 Mbps scenarios and gain flatness testing
   b. Ka-band 300 Mbps on KaSAR 650 MHz-wide channel tests, Ka-Band 300 Mbps on KaSAR 225 MHz-wide channel tests, and Ku-band 300 Mbps on KuSAR 225 MHz-wide channel tests
   c. Demonstration Ka-Band Transmitting System Characteristics Testing

6. As described in section 7.2, the 13.725 GHz CW Interference anomaly has been thoroughly analyzed and a solution has been selected. WSC has started the process to make the necessary 650 MHz downconverter LO changes in order to implement the selected solution.

7. The Code 564 receiver can support 600 Mbps through the SN.

8. Within the scope of this type of demonstration test and as Table 6-10 depicts, the predicted end-to-end implementation loss values are very close to the measured end-to-end implementation loss values.

Section 11. Acronyms

AGC	Automatic Gain Control
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BERTS	Bit Error Rate Test System
CW	Continuous Wave
DSMC	Data Service Management Center
EET	End-To-End Test
EIRP	Effective Isotropic Radiated Power
ESA	European Space Agency
FOTS	Fiber Optic Transmission System
GN	Ground Network
GSFC	Goddard Space Flight Center
HDR	High Data Rate
HDRR	High Data Rate Receiver
IF	Intermediate Frequency
IFL	Intra-Facility Link
ITU	International Telecommunications Union
KaSAR	Ka-Band Single Access Return
KaTP	Ka-Band Transition Product
KaSA	Ka-Band Single Access
LEO	Low Earth Orbit
LNA	Low Noise Amplifier
LO	Local Oscillator
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
PMP	Product Management Plan
PN	Pseudo-noise
POC	Point Of Contact
PRBS	Psuedo Random Bit Stream

QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RHCP	Right-Hand Circular Polarized
SA-1	Single Access-1
SGL	Space-Ground Link
SGLT-2	Space-Ground Link Terminal-2
SHO	Scheduling Order
SN	Space Network
SNIP	Space Network Interoperability Panel
SNR	Signal-to-Noise Ratio
SPW	Signal Processing WorkStation
SQPSK	Staggered Quadrature Phase Shift Keying
SRD	System Requirements Document
STGT	Second TDRSS Ground Terminal
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TT&C	Tracking, Telemetry, and Command
TWTA	Traveling Wave Tube Amplifier
WFF	Wallops Flight Facility
WSC	White Sands Complex
WSGT	White Sands Ground Terminal